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## Properties of $He^3$

D. TER HAAR
*Purdue University, Lafayette, Indiana*

DURING recent years, helium has come close to the center of scientific attention, partly because of the growing number of cryogenic laboratories in the United States, and partly because of the availability of enriched mixtures of $He^3$ and $He^4$. Slowly the results of experiments with these mixtures or even with the pure light isotope are being published. It may therefore be of interest to discuss from a theoretical point of view what kind of behavior we may expect from $He^3$, and to compare these expectations with the experimental results which are already available.

First of all, let us recall why experiments with helium are of such a great importance for an understanding of the laws of nature. It is well known that the behavior of a gas can be described accurately by classical thermodynamics as long as the chemical potential of the gas is large and negative. However, as soon as the chemical potential is in the neighborhood of zero, quantum effects become important. If we denote the chemical potential by $\nu kT$, in the customary notation, the condition for the applicability of classical statistics is

$$e^{\nu} \ll 1. \tag{1}$$

For $e^{\nu}$ we have, as long as Eq. (1) is satisfied,

$$e^{\nu} = \frac{p}{CM^{3/2}T^{5/2}} = \left(\frac{h^2}{2\pi mkT}\right)^{3/2} \frac{\rho}{m}, \tag{2}$$

where $C$ is the chemical constant,[1] $\rho$ the density, $p$ the pressure, $M$ the molecular weight, and $m$ the mass of one atom of the gas. Evaluating $e^{\nu}$ for various gases at their boiling points, we get the data of Table I, from which we see that the only gas for which serious deviations from classical behavior can be expected is helium. For $He^4$, it turns out that the quantum-mechanical corrections are of considerable importance. The agreement between experimental[2] and theoretical[3] values of the second virial coefficient at low temperatures is very good, but it is as yet impossible to draw from the experimental results the conclusion that $He^4$ obeys Bose-Einstein statistics. Since the value of $e^{\nu}$ is so much larger for $He^3$, it would be very important to repeat Kistemaker's experiments with $He^3$ since it might be possible to see from the behavior of the second virial coefficient whether $He^3$ does or does not follow Fermi-Dirac statistics. Kistemaker was not able to measure below about 1.8°K since the vapor pressure of $He^4$ is only 1.23 cm of mercury at this temperature. However, at 1.2°K the vapor pressure of $He^3$ is still 2 cm of mercury so that it should be possible to measure down to temperatures as low as 1.3°K or perhaps even 1.2°K. From a theoretical point of view it would be necessary to repeat the calculations of the second virial coefficient using the different mass

[1] For a definition of the chemical constant and for a derivation of Eq. (2) see, for instance, E. H. Kennard, *Kinetic theory of gases* (McGraw-Hill Book Co., Inc., New York, 1938), pp. 402, 407.

[2] J. Kistemaker and W. H. Keesom, *Physica* **12**, 227 (1946).

[3] J. de Boer and A. Michels, *Physica* **6**, 409 (1939).

TABLE I. Values of $e^{\nu}$ for different gases.

| Gas | Boiling temperature | $e^{\nu}$ |
|---|---|---|
| Argon | 87.4°K | 0.000002 |
| Neon | 27.2°K | 0.0001 |
| Hydrogen | 20.3°K | 0.007 |
| Helium (isotope 4) | 4.2°K | 0.13 |
| Helium (isotope 3) | 3.2°K* | 0.4 |

* For $He^3$, we have used the boiling point as given by Sydoriak, Grilly, and Hammel (see Ref. 9).

of the $He^3$ atom in the Schrödinger equation. A first rough estimate[4] shows that the situation is, indeed, much more favorable for $He^3$, not only because of the larger vapor pressure but also because of the fact that the difference between Fermi-Dirac and Bose-Einstein statistics, which can only be detected at 1.7° to 1.8°K for $He^4$ might well show up in the neighborhood of 2.3°K for $He^3$. It is probably a good approximation to use for the law of force between $He^3$ atoms the same as that between the $He^4$ atoms. The corrections due to a lighter nucleus and the spins of the nuclei will probably be negligible. Furthermore, it might be very interesting also to measure the second virial coefficient of $He^3$ at higher temperatures and to compare these data with the same data for $He^4$. The second virial coefficient determines the law of force[5] and any difference between the two laws of force should be observable in a difference between the second virial coefficients.

If, as should be expected, the laws of force between $He^3$ and $He^4$ atoms should be the same, it should be possible to use for many properties of $He^3$ the law of the corresponding states in its quantum-mechanical form. This law and its consequences have been studied extensively by de Boer and collaborators.[5,6] If the potential energy $U(r)$ between two atoms of a gas as a function of the distance apart $r$ of the two atoms is given by the equation

$$U(r)=\epsilon f(r/\sigma), \tag{3}$$

where different gases differ only in the values of $\epsilon$ which has the dimensions of an energy, and $\sigma$ which has the dimensions of a length, while $f(r/\sigma)$ is the same for all gases, the law of corresponding states can be stated as follows:[7] Introducing reduced quantities for temperature, pressure, and specific volume by

$$p^*=p\sigma^3/\epsilon, \quad T^*=kT/\epsilon, \quad V^*=V/N\sigma^3, \tag{4}$$

where $N$ is Avogadro's number, the reduced equation of state will be a universal relation:

$$p^*=F(V^*, T^*). \tag{5}$$

The proof of this statement follows easily by the usual statistical methods.[6] Equation (5), however, holds only as long as quantum effects can be neglected. If quantum effects have to be taken into account, we have to introduce one more reduced quantity

$$\Lambda^*=h\sigma^{-1}(m\epsilon)^{-\frac{1}{2}}, \tag{6}$$

and the reduced equation of state has the form

$$p^*=F(V^*, T^*, \Lambda^*). \tag{7}$$

De Boer and Lunbeck[8] have used this law of corresponding states to predict the critical temperature and pressure of $He^3$ and its vapor pressure as a function of temperature. This was done in the following way. If no quantum effects were present, all gases obeying the law of force (3) should have the same critical values of $T^*$ and $p^*$. However, due to the appearance of $\Lambda^*$ in Eq. (7) this is no longer true. We can, however, plot $T_{cr}^*$ and $p_{cr}^*$ as functions of $\Lambda^*$ and in this way from the known value of $\Lambda^*$ for $He^3$ arrive at an estimate of its critical temperature and pressure. In Table II we have assembled the data given by de Boer and Lunbeck.[8] The last line carries the experimental values of $T_{cr}$ and $p_{cr}$ as determined by Sydoriak, Grilly, and Hammel.[9] We see that the law of corresponding states was indeed able to predict the critical data. The uncertainty of the predicted values

[4] D. ter Haar, *Physical Rev.* **75**, 1444 (1949). The last paragraph of this note is written badly. For hard spheres, which should be a good approximation since the actual potential curve is shallow, the second virial coefficient depends on the temperature in the combination "mass ×temperature" and any effect should therefore become discernible at a temperature one-third higher for $He^3$ than for $He^4$.

[5] J. de Boer and A. Michels, *Physica* **5**, 945 (1938).

[6] J. de Boer, *Physica* **14**, 139 (1948); J. de Boer and B. S. Blaisse, *Physica* **14**, 149 (1948); J de Boer and R. J. Lunbeck, *Physica* **14**, 520 (1948).

[7] As was emphasized by de Boer (see Ref. 6), the law in this form cannot replace the usual form of van der Waals and Kamerlingh Onnes, from which information could be obtained if only a few data about the gas were known. In its present form it can only be applied to gases for which $\sigma$ and $\epsilon$ are known.

[8] J. de Boer and R. J. Lunbeck, *Physica* **14**, 510 (1948).

[9] Sydoriak, Grilly, and Hammel, *Physical Rev.* **75**, 303 (1949).

for $He^3$ is due to the uncertainty of the extrapolation.

The vapor pressure curve above 2°K was derived by plotting for a given value of $p^*$ the values of $T^*$ as a function of $\Lambda^*$ and extrapolating to $\Lambda^*=3.05$ (the value for $He^3$). In this way, the $(p^*, T^*)$ curve was obtained. For temperatures of $He^3$ below 2°K, de Boer and Lunbeck give the formula[10]

$$\log_{10}p=-1.12/T+5/2\log_{10}T+1.01, \qquad (8)$$

obtained from a similar formula for $He^4$; the pressure $p$ is expressed in cm of mercury, and the coefficient of $1/T$ is proportional to the internal energy of the liquid at 0°K. The value of this internal energy was again derived by the extrapolation method.

In Table III, we give the values of the vapor pressure of $He^4$, as given by Keesom,[11] of $He^3$ as measured by Sydoriak, Grilly, and Hammel[9] and the theoretical values of de Boer and Lunbeck.[8] In the third column we give the values derived from the vapor pressure data of other gases, and in the fourth column the values calculated from Eq. (8). Although this equation should be valid for low temperatures only, we have used it up to the highest temperature given in Table III. Since de Boer and Lunbeck's values were calculated for temperatures different from those for which the vapor pressure was measured, we have interpolated the experimental data in order to be able to compare them with the theoretical values. It is seen that the agreement between the experimental and theoretical values is excellent, especially since the theory was made before the experiments and could not, therefore, have been influenced by them.

The $He^3$ used in these experiments was obtained from the $\beta$-decay of tritium made in the Los Alamos pile. The amount available for the experiment was 20 $cm^3$ under standard conditions. Both de Boer and Lunbeck, and Sydoriak, Grilly, and Hammel draw attention to the fact that $He^3$ could be used for obtaining low bath temperatures by pumping off the vapor since the vapor pressure of $He^3$ is so much higher than that of $He^4$. The higher vapor pressure of $He^3$ might also be used to enrich $He^3$-$He^4$ mixtures by fractional distillation at low temperatures, below about 1.3°K.

De Boer and Lunbeck also calculated by the usual thermodynamical methods the ratio of the relative concentration of $He^3$ in the vapor and the liquid. For temperatures above the $\lambda$-point of $He^4$, their theoretical curve agrees well with the experimental data.[12] Below the $\lambda$-point, however, the agreement is bad. This is not surprising since Lane, Fairbank, Aldrich, and Nier[13] have recently rediscussed their first experiments[12] and those of Daunt, Probst, and Smith[14] and found that due to the properties of $He^4$ below the $\lambda$-point, their own first results[12] were probably interpreted in a completely wrong way, and have to be corrected. With appropriate reinterpretation the results are in close agreement with measurements of Rollin and Hatton.[15]

The main interest of theoretical physicists will probably be concentrated on experiments with pure liquid $He^3$. As is well known, $He^4$ shows many extremely strange phenomena such as superfluidity, supraheat conductivity, Rollin film and fountain effect, which are all connected with He II, the form of liquid $He^4$ below the so-called $\lambda$-point.[16] The $\lambda$-point got its name from the

TABLE II. Critical data of different gases.

| Gas | $\Lambda^*$ | $T_{cr}^*$ | $p_{cr}^*$ | $T_{cr}$ | $p_{cr}$ |
|---|---|---|---|---|---|
| Xe | 0.064 | (1.26) | 0.122 | 289.8°K | 58.22 atmos. |
| Kr | 0.102 | (1.26) | 0.117 | 209.4 | 54.24 |
| A | 0.187 | 1.25 | 0.116 | 150.7 | 48.00 |
| $N_2$ | 0.225 | 1.30 | 0.132 | 126.0 | 33.49 |
| Ne | 0.591 | 1.26 | 0.114 | 44.8 | 26.86 |
| $H_2$ | 1.73 | 0.90 | 0.063 | 33.2 | 12.80 |
| $He^4$ | 2.64 | 0.51 | 0.027 | 5.25 | 2.26 |
| $He^3$ | 3.05 | 0.31–0.35 | 0.011–0.016 | 3.1–3.5 | 0.93–1.35 |
| $He^3$ | — | — | — | 3.34 (exp.) | 1.15 (exp.) |

[10] Equation (8) is the well-known thermodynamical vapoı pressure formula:

$$\log_e p=U_0/RT-\tfrac{5}{2}\log_e T-C-1/R\int_0^T (U/T^2)dT,$$

where $C$ is again the chemical constant, $R$ the gas constant, $U$ the internal energy, and $U_0$ the internal energy at absolute zero. The last term may be neglected for temperatures under consideration.

[11] W. H. Keesom, *Helium* (Elsevier Publishing Company, 1942).

[12] H. A. Fairbank, C. T. Lane, L. T. Aldrich, and A. O. Nier, *Physical Rev.* **71**, 911 (1947); **73**, 256, 729 (1948).

[13] C. T. Lane, H. A. Fairbank, L. T. Aldrich, and A. O. Nier, *Physical Rev.* **75**, 46 (1949).

[14] J. G. Daunt, R. E. Probst, and S. R. Smith, *Physical Rev.* **74**, 495 (1948).

[15] R. V. Rollin and J. Hatton, *Physical Rev.* **74**, 508 (1948).

[16] For a survey of these phenomena the reader is referred to Keesom's monograph (see Ref. 11) or E. F. Burton,

TABLE III. Vapor pressure of $He^3$ in cm of mercury.

| $T$(°K) | $He^4$ | $He^3$ (exp.) | $He^3$ (theor.) | |
|---|---|---|---|---|
| 1.21 | 0.07 | 2.3 | — | 2.0 |
| 1.33 | 0.14 | 3.2 | — | 3.0 |
| 1.52 | 0.39 | 5.4 | — | 5.3 |
| 1.63 | 0.64 | 7.1 | — | 7.1 |
| 1.8 | 1.23 | 10.0 | — | 10.7 |
| 2.0 | 2.34 | 14.7 | 14 | 16 |
| 2.4 | 6.26 | 28.6 | 27 | 31 |
| 2.8 | 13.27 | 48.5 | 48 | 54 |
| 3.0 | 18.12 | 61.4 | 59 | 68 |
| 3.2 | 24.05 | 76.4 | 75 | 83 |
| 3.3 | 27.48 | 84.4 | 82 | 93 |

shape of the specific heat curve of liquid helium. In the following, we wish to discuss briefly which properties of He II may also be expected to be present in liquid $He^3$.

F. London[17] suggested that the λ-transition would be the Einstein-condensation of an ideal Bose-Einstein gas. There seem, however, to be arguments against, as well as in favor of, this idea. It is questionable whether any density fluctuations, which should be present in the case of an ideal Bose-Einstein gas, could easily be observed. However, Wergeland[18] has, for instance, shown that strong interatomic forces will completely destroy the Bose-Einstein character of a crystal. Also, the shape of the specific heat curve, which should be the strongest support of London's theory, is definitely different from the curve for an ideal Bose-Einstein gas. Tisza's recent attack on the problem[19] seems to be more promising. He sees in the λ-transition a Bose-Einstein condensation of the shear modes of motion, that is, the various modes of motion of the liquid are treated as a gas, while the atoms themselves are treated like a liquid. Tisza[16] remarks that the indications that $He^3$ is not superfluid justifies to some extent the idea connecting superfluidity with the Bose-Einstein statistics of the *atoms*. This, however, seems to the present author not to do justice to his own theory. It would be expected that $He^3$ should also show the Bose-Einstein condensation of shear modes, notwithstanding the fact that each $He^3$ atom obeys Fermi-Dirac statistics, in the same way as the Fermi-Dirac gas of electrons will show ferromagnetism as a Bose-Einstein condensation—a phenomenon discussed by Bloch. The present author is inclined to accept Tisza's theory as a promising working hypothesis but also expects a λ-transition to exist for $He^3$.

A difficult question is, how this λ-transition could be observed. It should certainly show up as a discontinuity in the specific heat curve, and it certainly would be worth while to measure the specific heat of $He^3$. A fast way of getting an indication whether or not a λ-shaped curve for the specific heat exists was drawn to the present author's attention by Professor W. H. Keesom.[20] If by pumping one lowers the pressure above the $He^3$ bath, the temperature will drop. This drop will take place continuously until the λ-temperature is reached when the sudden increase in specific heat should cause the temperature to remain constant for a certain period before further decreasing. Provided the law of corresponding states is applicable, we should expect the λ-temperature to be much lower than that of $He^4$. It might easily lie as low as 1.3 or 1.4°K.

If we assume that $He^3$ will show a λ-transition, then there are still strong reasons to suspect that $He^3$ will not show superfluidity, film effects, and so on. The λ-phenomenon of $He^3$ may be observable only in the less spectacular properties such as the specific heat, heat of vaporization, and dielectric constant. The superfluidity of $He^4$ is usually attributed to two factors: first, the absence of dynamic viscosity,[19] second, the presence of a "superfluid" state of $He^4$ below the λ-point. The viscosity is of the kinetic type[19] which will decrease with temperature and this effect combined with the increasing percentage of "superfluid molecules" will give rise to the observed low viscosity of $He^4$ below its λ-point. For $He^3$, however, the situation is completely different. Up to now, all experiments which should show the absence of superfluidity in $He^3$ have been performed at temperatures rather higher than the above estimate of the $He^3$ λ-point, though much lower than the λ-point of $He^4$. In these experiments, performed by Daunt

H. Grayson Smith, and T. O. Wilhelm, *Phenomena at the temperature of liquid helium* (Reinhold, New York, 1940), or to more popular accounts such as: J. Kistemaker, *La Revue Scientifique* **86**, 176 (1948), or L. Tisza, *Physics Today* **1**, No. 4, 4 (1948).

[17] F. London, *Nature* **141**, 643 (1938); *Physical Rev.* **54**, 947 (1938); *J. Physical Chem.* **43**, 49 (1939).

[18] H. Wergeland, *D. Kgl. Norske Vid. Selsk. Forh.* **19**, 80 (1947).

[19] L. Tisza, *Physical Rev.* **72**, 838 (1947).

[20] See also W. H. Keesom, Ref. 11, p. 221.

and his collaborators[21] at Ohio State University, and Taconis[22] at the Kamerlingh Onnes Laboratory in Leyden, an enrichment of $He^3$ was achieved by letting part of the $He^4$ disappear through capillaries which were so thin that only a superfluid could pass. This method was suggested by Franck[23] as a possible means of separation and at the same time as a possible means of testing the connection between superfluidity and statistics. It would be very interesting to perform the same experiments at a much lower temperature, in the neighborhood of 1°K. However, it seems to us that even at these low temperatures $He^3$ would not show superfluidity, due to the "background" viscosity of the Fermi-Dirac particles. The "superfluid molecules" which, in the case of $He^4$, might be compared to *eels* slipping through the system, would be more like *porcupines* in the case of $He^3$. If this picture is correct, one should neither expect supraheat-conductivity, film and similar effects since these effects depend on the ease with which the "superfluid molecules" slip through the system. Wergeland and the present author[24] have calculated the viscosity of mixtures of $He^3$ and $He^4$ on the specific assumption that this background viscosity is an important factor. An experimental check of these theoretical predictions might give an indication of the influence of this background effect. However, the absence of superfluidity in $He^3$ does *not* necessarily mean that $He^3$ does not show a λ-transition or that the λ-transition of $He^4$ is due to its Bose-Einstein character.[25]

Summarizing, we can say that for liquid $He^3$ there are three possibilities. (1) The λ-phenomenon is really due to the statistics of the $He^4$ *atom*, and $He^3$ will not show the λ-transition. (2) The λ-phenomenon is due to the Bose-Einstein statistics of the *modes of motion*, and $He^3$ will show a λ-phenomenon, although the more spectacular effects are drowned by the background viscosity. (3) $He^3$ shows a λ-transition with all its implications. To decide between the last two possibilities, Daunt's experiments should be extended to temperatures well below the possible λ-point of $He^3$ which might lie in the neighborhood of 1.4°K.

For gaseous $He^3$, the measurement of the second virial coefficient for temperatures in the neighborhood of 1.5°K or even lower would be of great theoretical interest.[26]

[21] J. G. Daunt, R. E. Probston, H. L. Johnston, L. T. Aldrich, and A. O. Nier, *Physical Rev.* **72**, 502 (1947); J. G. Daunt, R. E. Probst, and H. L. Johnston, *J. Chem. Physics* **15**, 759 (1947).

[22] K. W. Taconis, J. J. M. Beenakker. Alfred O. Nier, and L. T. Aldrich, *Physical Rev.* **75**, 1966 (1949).

[23] J. Franck, *Physical Rev.* **70**, 561 (1946).

[24] D. ter Haar and H. Wergeland, *Physical Rev.* **75**, 886 (1949).

[25] See also: L. Landau, *Physical Rev.* **75**, 884 (1949); L. Tisza, *Physical Rev.* **75**, 885 (1949).

[26] After this paper was written, Osborne, Weinstock, and Abraham (*Physical Rev.* **75**, 988 (1949)) published results of measurements of flow of pure $He^3$. Their results show that down to 1.05°K, $He^3$ is not superfluid. This should eliminate case (3) mentioned above. However, as we pointed out before, this does *not* necessarily mean that the λ-point transition of $He^4$ is due to the Bose-Einstein statistics of its *atoms*: contrary to the opinion expressed in the paper of Osborne, Weinstock, and Abraham.

## Wisconsin Section

At the annual meeting of the Wisconsin Section of the American Association of Physics Teachers held at Lawrence College, Appleton, Wisconsin, on Friday and Saturday, May 6 and 7, 1949, the following officers were elected to serve the year 1949–50: *President*, E. H. SCHREIBER, *State Teachers College, Superior, Wisconsin; Vice-President*, V. P. BATHA, *Carroll College; Secretary-Treasurer*, W. P. CLARK, *State Teachers College, Eau Claire, Wisconsin; Regional Representative on the AAPT Executive Committee*, R. R. PALMER, *Beloit College*.

—W. P. CLARK, *Secretary-Treasurer*.

# The Development of American Physics*

E. U. Condon
*National Bureau of Standards, Washington, D. C.*

I HAD an informal understanding with our Secretary that my address was to cover the growth of physics in the last fifty years, But, now that the program is out, I see that the title has been changed to read, The Development of American Physics. I happen to be one of those who never went along with the idea of a distinctly racial or regional attitude toward our science, even when put forth by such eminent authorities as Hitler or Goebbels. I think it would be provincial of me consciously to stress the American side of the story, although this will undoubtedly happen because we are all products of our environment.

It would be easy indeed to fill up my time with a lot of specific instances of the way in which experimental physics has moved out of the horse-and-buggy age—of the age of simple little apparatus put together by one man with "love and string and sealing wax"—and of how it has moved into a gigantic affair of multimillion dollar electronuclear machines requiring great teams of trained men in various specialties for their design, construction and operation.

It would also be easy indeed to fill up the time with a lot of specific instances of the way in which, during the past half-century, new branches of applied physics have given rise to whole new industries, such as the widespread use of electric power, the telephone, the radio, television, x-rays and radiation therapy in general, the use of radioactive materials as tracers in chemistry, the deeper understanding of the solid state, and its associated technical improvements in metals, magnetic materials, photoelectric emitters, semiconductors, insulating materials, and so on and so on—using up the entire forty-five minutes allotted to me with the mere listing of important topics.

It would, moreover, be easy indeed to fill up the time with dates and specific items about the growth of theoretical physics. Fifty years ago even Max Planck had not heard of Planck's constant, nor had Lorentz heard of the Lorentz contraction, nor had Einstein heard of the theory of relativity. For that matter, forty years ago Bohr had not heard of the Bohr atom, nor had von Laue heard of the diffraction of x-rays by crystals. Thirty years ago Hess and Millikan were just beginning to recognize that cosmic rays come from outer space, and as for Dirac, he was just a boy in school.

Twenty years ago we were all just beginning seriously to grapple with the ideas and experimental consequences of quantum mechanics. Only a short time before, Goudsmit and Uhlenbeck had introduced the idea of electron spin and Pauli had enunciated the Pauli exclusion principle which was the last major step in clarifying our basic ideas of the analysis of atomic spectra. Twenty years ago was when we first began to realize not only that the wave nature of matter would manifest itself in diffraction of electrons and other atomic particles, but that it also made it possible for particles to leak through potential barriers even though they did not have energy enough to go over the top—a process which if discovered today might be called *infiltration*. Twenty years ago Chadwick had not discovered the neutron, nor had Urey discovered deuterium. Nor had Irene Curie and Frederic Joliot discovered artificial radioactivity, nor had Pauli and Fermi balanced the books in beta-decay processes by inventing the neutrino, nor had Yukawa thought of the mesotron. And yet all of these things were to happen within a very few years, so that twenty years ago we stood on the very threshold of the recent very great advances in our knowledge of nuclear physics.

Ten years ago we were pretty well equipped with general ideas about nuclear physics and by that time we had developed some fine equipment which was available for experimental work. Besides the sledge-hammer boys with their Van de Graaff generators and cyclotrons, there were also the watch-maker boys like Rabi at Columbia and Bloch at Stanford who were learning precise and

* Address delivered at semi-centennial meeting of the American Physical Society, Harvard University, Cambridge, Massachusetts, June 17, 1949.

interesting things about nuclei by the gentlest of methods. Ten years ago we had just learned of the discovery of uranium fission, when Bohr brought the news to a physics conference in Washington from the Berlin laboratories of Otto Hahn in January 1939.

Ten years ago we were just beginning to recognize that—if certain as yet not accurately measured parameters had suitable values—it might be possible to produce a slow neutron chain reaction using uranium fission to release atomic power, or to produce a fast neutron chain reaction leading to a military weapon of quite unprecedented destructiveness. This was the time of our first encounter with top policy in government and politics. Probably things will never again be the same for us in this respect. This, I think, is a good thing for it has helped to give many of us a better insight than we had before into the complexities and duties of responsible citizenship in a democracy.

It would be easy to fill up more than the allotted time—some of which must already have gone by—with the development of this theme. But there is not time enough for that either.

Since our whole subject is clearly too big to be dealt with by the method of enumeration and brief description of even a few of the main lines of specific development, how then, shall we deal with it? I would like to try to touch on a few very broad considerations affecting the significance and role of physics in the world of modern thought, and the changes which have come about during the period in question as to the methods of theoretical physics, and the expanding development of our ideas of what constitutes progress toward *explanation* in physical science.

The past half-century has seen enormous change with regard to these matters although they are more apt to escape our attention because such ideas and trends are more subtle than the specific, concrete phenomena which we treat in articles for the *Physical Review.* It seems to me that the greatest change which has occurred in the past half-century in this broad light, has come in the recognition generally that the framework of ideas of classical Newtonian mechanics is inadequate as a basis for the description of all physical phenomena. The modern scientific period in physical science is only about three centuries old and, as we know, owes its strength and main initial impetus to the formulation of Newtonian mechanics, and the enormous success of Newtonian mechanics in explaining the motions of the moon and the planets. The Newtonian concept was then rapidly extended to dynamical systems of all kinds, including fluid and elastic systems.

Its successes were so great that many men jumped to the conclusion that all physical phenomena must be ultimately describable in such terms. Thus, it was natural in the middle of the nineteenth century that Lord Kelvin and others should seek to find an explanation of the second law of thermodynamics in terms of dynamical models involving hidden cyclic variables—not with the statistical concept as we know it from Boltzmann and Willard Gibbs. Likewise Maxwell sought a completely dynamical model of the electromagnetic field in which neighboring elements of space were regarded as being somehow in a state of strain and as acting on each other by dynamical connections. We have come so far away from that point of view in this century that I dare say that many of the younger physicists of today are hardly aware of the emphasis which Maxwell placed on the mechanical model of the medium which propagates electromagnetic effects.

Historically the first great addition to the purely dynamical idea was made in the development of statistical mechanics by Gibbs and by Boltzmann. Here the notion of a statistical ensemble of possible states of a system is introduced in order to arrive at a quantitative model for the observable property, entropy. So far as I can make out from the older literature, the fact that this step revealed the inadequacy of Newtonian mechanics for dealing with thermodynamics was not recognized very fully at the time. This came about, I suppose, because there still seemed to be the possibility of giving a full and complete description of complicated molecular systems by ordinary mechanics, in principle at least. Therefore, there was a certain tendency to regard the statistical part as a temporary expedient, a kind of scaffolding which could be removed when the construction was far enough along. However, that is not correct, for entropy is a physically observable attribute of matter

which requires the statistical method for its description.

In the first few years of the century we find the modern attitude in electrodynamics gradually forming. More and more there is observed a tendency to study the properties of the field equations and the relation of special solutions to specific observational situations. In this process we find physicists more and more concerned solely with getting a suitable self-consistent set of equations that describe and correlate observable effects, and spending less and less time considering what sort of dynamical constitution the hypothetical aether must have in order to be governed by such equations.

Prior to this century Maxwell made the first application of what has since become a very powerful method in theoretical physics. The known phenomena, first studied by Ampere, concerning the magnetic fields due to galvanic currents, were represented by the equations

$$\mathrm{curl} H = 4\pi i,$$

where $H$ is the magnetic field strength and $i$ is the current density in electromagnetic units. Maxwell recognized that this equation could not be complete because $\mathrm{div}\,\mathrm{curl} H \equiv 0$, identically. On the other hand, the equation $\mathrm{div} i = 0$ only holds exactly when the currents are steady. Therefore, Maxwell argued, the quantity $i$ must be replaced by some more general expression which reduces to this in case the currents are steady.

A simple exploration of known relations showed that the simplest physical quantity which reduces to $i$ under steady conditions, and whose divergence is zero under all conditions is

$$i + \dot{E}/4\pi c$$

where $\dot{E}$ is the time rate of change of the electric field and $c$ is the ratio of electromagnetic and electrostatic units. He therefore boldly guessed that this was the proper term to replace $i$ under nonsteady conditions. By this purely formal consideration he was able to make an extension of incomplete field equations in a way which led to the prediction of electromagnetic waves and a description of their properties, hence to radio, and the whole electromagnetic theory of light.

The next great step of this kind was taken by Einstein in 1905 when he formulated the principle of relativity. He found that the transformations between the reference systems of different observers in differing states of relative motion with constant relative velocity which were applicable in electrodynamics were different from those which were applicable in classical mechanics. It also appeared that the experimental data, of an optical kind, favored the validity of the electromagnetic scheme of transformation rather than that indicated by classical mechanics. Therefore, he had to seek a way to modify the Newtonian equations so that they would be governed by the Lorentz transformations but would nevertheless reduce to ordinary classical mechanics when all velocities were small compared to that of light.

From that time on, the method was fully established as a basic tool for construction of new theories in physics. The basic principle involved may be stated something like this: If we have really discovered the appropriate kind of mathematical framework for a given situation, then the actual law of nature will usually be found to be the simplest of the various mathematical possibilities consistent with the known requirements.

Thus, in Einstein's general theory of relativity, it is recognized that gravitational fields are describable by the introduction of a general Riemannian curvature tensor for the four-dimensional space-time. But this consideration alone is not specific enough to be definite. The simplest additional mathematical condition is to require that the contracted Riemann-Christoffel curvature tensor shall vanish. And, it seems, this is the law which gives the correct description of gravitational phenomena.

In the modern period of the last twenty-five years, this method has been extraordinarily fruitful. Schrödinger discovered the specific equations of wave mechanics by the simplest heuristic considerations of this sort once he was on the trail of having a wave mechanics. Perhaps its most striking and powerful achievement was its use by Dirac when he set up the simplest appropriate relativistic wave equation for the electron, and showed that this automatically brought with it the properties of spin and the prediction

of the existence of the positron. The whole theory of mesons and meson fields is a construction of this kind. The main trouble here seems to be that with this mathematical tool the younger generation of theoretical physicists is so facile at constructing new theories that we have an embarrassment of riches.

Closely related to this general idea, but somewhat more special, has been the growth of the broad idea of invariance in physical theories. This got into physics first in general terms leading to the development of vector and tensor analysis, designed to give expression to the experimental fact of the isotropy of space. This is expressed by requiring that all equations be of such a kind that their form is invariant when referred to a second set of coordinates oriented in an arbitrarily different way relative to the first frame.

This is where the mathematical theory of groups makes its entry into physics. The different possible frames of reference which are observed to be physically equivalent are connected to each other by transformations. These transformations form the elements of a group. All quantities and relations entering into any physical theory must transform like one of the representations of the group. This principle serves in a broad way to limit, select and control the mathematical forms which may be used in building theories. First we recognized invariance with respect to the group of Euclidean rotations of axes, then with respect to the larger group which includes Lorentz transformations. Then we had to deal with the more special symmetry groups applicable to the description of symmetric molecules or to crystalline structures. Finally, in the case of systems consisting of many identical, and therefore indistinguishable particles, our equations must possess invariance with respect to interchanges or general permutations of such particles.

However, we must be on guard against assuming that invariance properties which hold in one field of physics must necessarily hold in every other branch of physics. Invariance is a broad generalization from experiment for a certain class of phenomena, and this does not exclude the possibility that the invariance does not obtain with regard to some other phenomena. Thus, rocksalt is isotropic with regard to refraction of ordinary light, but far from isotropic with regard to diffraction of x-rays. Again, I would be greatly surprised if the basic equations of short-range nuclear forces should turn out not to be Lorentz-invariant, but I do not think we have any experimental evidence today that definitely requires that they do have this property. This whole broad discipline of invariance under a group of transformations is one of the fruitful ideas that is essentially characteristic of the modern theoretical physics of this century.

In passing we may note that some broad ideas which in earlier times were thought to be of great significance seem nowadays to be less fruitful than formerly it was expected they would be. In this category I would put the whole class of variational principles. While people still like to show how their field equations can be derived from a variation principle, that is, the stationary property of some field integral, this general connection does not seem to have been really fruitful in guiding us to new results in physics.

So much for some general characteristics of the modern point of view in the construction of physical theories. I would like to close by commenting briefly on the general question: What is the intellectual goal of physics? More specifically, what do we mean when we *explain* something in physics? This used to mean that we had successfully correlated the observed phenomena with the behavior of some mechanical model behaving according to Newtonian principles. And for a long time, extending well into this century, many of the older physicists insisted that phenomena were not *explained* unless they had been explained in this sense. But we have seen that the construction of theories in modern physics has gone far beyond that limitation, and so we must ask for a fuller description of what we mean by explanation.

It seems to me that in this direction, too, our half-century has seen a great deal of progress, or at least change toward a more sophisticated outlook. In this the American philosopher John Dewey has played a great role, as has also our past-president and one of our Harvard hosts, Percy Bridgman.

Dewey points out clearly that the growth of

rational thought processes may be considered as a response to the biological necessity of adaptation to the environment. Its ultimate function, he says, is that of "prospective control of the conditions of the environment." It follows then, continuing to quote, that: "The function of intelligence is therefore not that of copying the objects of the environment, but rather of taking account of the way in which more effective and more profitable relations with these objects may be established in the future."

Bridgman's critique of the concepts and procedures of physics is built on an insistence that maximum emphasis be placed on the idea that the concept must be identical with and fully determined by the physical procedures which we actually employ in observing the quantity which expresses the concept. His critique also illustrates one of the characteristic modern attributes of theoretical physics in its strong insistence on elimination of any kind of dependence on nonessential or adventitious elements in a theory.

What then remains? Once eleven years ago I attempted to answer this question for myself and came up with the following statement which I still think is a good working basis for considering the subject:

> The object of physics is so to organize past experience with relation to matter and energy, and so to direct the acquisition of new experience, that we may advance toward a goal in which it may ultimately be possible to predict the outcome of any proposed experiment which is capable of being carried out—and to make the prediction with the expenditure of less human effort than it would take actually to carry out the proposed experiment.

This statement you will see is well-hedged. I do not say that we can ever reach the goal, but certainly the experience of the past fifty years has shown a great deal of advance toward it. And you will observe that I restrict the field of predictions to experiments which are capable of being carried out. And finally that the whole activity is clearly tied in with the pragmatic function of developing intelligence in giving us a more economical way to know about our physical environment than by making the trial each time.

It is an exciting and challenging game. It is lots of fun being a physicist, and I am sure the physicists are going to have a lot of fun in the next half-century if they are allowed to work at physics.

## Films Selected for First-Year College Physics

Robert L. Weber
*The Pennsylvania State College, State College, Pennsylvania*

THE extensive use of the film as a training and propaganda medium in the war led educators to speculate upon the importance of the film in postwar education. Some felt that the film "could be a magnificent adjunct to educational media in peacetime. We may well be at the beginning of a revolution in teaching and demonstration techniques."[1]

The potential values of the film for physics instruction are obvious and attractive. Demonstration experiments presented by means of motion pictures rarely fail to exhibit the intended effects. The demonstrations can be shown with economy of time and effort in a form easily visible to all, with animated drawing and carefully planned oral description to clarify the phenomena and the physical concepts. The phenomena may include many that, for a variety of reasons, cannot be demonstrated at the lecture table.

Despite these advantages, instructors who have used films in the teaching of college physics have noted chiefly their shortcomings The inadequacy stems in part from the nature of the medium. A film presentation is usually inflexible, but need not be so. The realism of actual demonstrations is missing, the student is allowed little opportunity for reflection, questions, or the

[1] Scientific Films in Teaching Physics, *Nature* **150**, 691 (1942).

taking of notes. There is a lack of repetition and no opportunity for individual students to review and study the film.

Other and more remediable inadequacies in the present use of instructional films in college are: (1) the diffuseness and theatrical packing of films edited to catch the widest possible audience; (2) the limited effort of colleges and professional organizations to sponsor and edit films for specific teaching needs; (3) the difficulty of finding reliable critical appraisals of films; and (4) the inconvenience to the instructor of screening films in advance and fitting them effectively in the classroom work.

A basic defect is the failure of producers to test or prove their films before releasing them. Generally it is not known whether or not and to what degree films teach what the sponsors and producers hope they will teach. Prerelease testing is needed.

In overcoming these inadequacies, we have the guidance of experimental studies of the teaching value of certain widely used films.[2] Even more beneficial are the efforts of film research groups in determining, by audience-controlled experiments, the picture and sound techniques best suited to the purpose of a proposed film, as specified by its sponsors.[3]

The AAPT Committee on Visual Aids to Teaching reported at the January, 1949 meeting of the Association a plan to produce films on nuclear power for college physics classes. We can hope that this marks the beginning of a successful project of our Association in combining competent editing with the improved knowledge of film techniques and recently achieved economies of production to provide superb films for college instruction in physics.

Following the committee's report, there were numerous inquiries from the audience regarding existing films. These inquiries emphasized the inadequacies numbered (3) and (4) above, and are the occasion for submitting this paper. Some of the standard film guides[4] include outlines and appraisals of the films listed. These are usually not sufficiently critical to relieve the instructor of responsibility for personally checking a film for suitability and accuracy before a classroom showing. Otherwise he may find that a ten-minute film may actually undermine the careful instruction of several lessons. It may produce a negative effect on learning.

The first of a series of reviews intended to provide reliable information concerning films available for physics instruction, which appeared in this journal,[5] is the sort that would be very helpful to teachers. Perhaps if there were a sufficient number of requests, the service could be resumed.

Meantime, the following list of physics films is presented. They were selected as readily available, reasonably accurate, and relatively free of extraneous material. Few are ideal. Those marked

[2] C. J. Lapp, "Some experiments on the teaching value of sound films in college physics," *Am. Physics Teacher* **7**, 172–173 (1939).

C. J. Lapp, "The effectiveness of a sound motion picture 'Electrodynamics' in college physics," *Am. Physics Teacher* **7**, 224–230 (1939).

C. J. Lapp, "A study of the teaching effectiveness of the sound motion picture, 'Light waves and their uses,'" *Am. J. Physics* **8**, 67(A) (1940).

C. J. Lapp, "The teaching effectiveness of the sound motion picture 'The electron,'" *Am. J. Physics* **9**, 112–116 (1941).

[3] C. R. Carpenter, "A challenge for research," *Educational Screen*, March 1948.

C. R. Carpenter, "Requirements of research on instructional films," *Hollywood Quarterly* **3**, No. 3, 262–266, Spring 1948.

Progress Reports, Instructional Film Research Program (Dr. C. R. Carpenter, Director), The Pennsylvania State College School of Education, U. S. Navy Task Order VII, Contract N6onr-269.

[4] Dorothy E. Cook and Katherine M. Holden, *Educational Film Guide* (H. W. Wilson Company, 950 University Ave., New York 52) includes appraisals and directory of distributors.

EFLA Film Ratings (Educational Film Library Association, suite 1000, 1600 Broadway, New York 19) a card index with appraisals.

*Films for Classroom Use* (Teaching Film Custodians, Inc., 25 W. 43 St., New York).

*Films from Britain* (British Information Services, 30 Rockefeller Plaza, New York 20).

Mary F. Horkheimer and John W. Diffor, *Educators Guide to Free Films* (Educators Progress Service, Randolph, Wisconsin).

*One Thousand and One—The Blue Book of Non-Theatrical Films* (The Educational Screen, 64 E. Lake St., Chicago 1) annual editions.

Scientific Film Association, compiler, *Catalogue of Films of General Scientific Interest Available in Great Britain.* 1946 (Aslib, 52 Bloomsbury St., London, W.C. 1) includes appraisals.

*Selected Educational Motion Pictures, A Descriptive Encyclopaedia.* 1942 (American Council on Education, Washington, D. C.) includes appraisals.

*Films for America at War.* Supplement No. 1 to S.E.M.P. 1942.

*Sources of Visual Aids for Instructional Use in Schools.* Pamphlet No. 80, U. S. Office of Education, Washington 25, D. C.

[5] Walker Bleakney, "Motion pictures," *Am. Physics Teacher* **2**, 122 (1934).

with an asterisk are least liable to be disappointing in providing effective summaries of topics included in most college physics courses.

The films in this list are 16-mm sound films in black and white, unless otherwise designated. Each title is followed by the name of the producer or the principal distributor from whom the film can be obtained. Addresses are given at the end of the film list. In many cases the films can also be borrowed from local film distributors or from university film libraries.

Coordinated slidefilms and instructor's manuals are available for all of the U. S. Office of Education films. In many cases instructor's manuals for other films are obtainable on request.

## Introduction

| | Decimal classification |
|---|---|
| **Matter and energy.** 10 min, b&w or color, (1947). Coronet. | 531 |
| **The micrometer.** 12 min, (1942). USOE, Castle. | 389 |
| **Precisely so.** 20 min, (1940). General Motors. | 600 |
| ***The slide rule (multiplication and division).** 24 min, (1944). USOE, Castle. | 510.78 |
| **The slide rule (percentage, proportion, squares and square roots).** 21 min, (1944). USOE, Castle. | 510.78 |
| **Time.** 20 min, (1944). Modern. | 681 |
| **Verniers.** 19 min, (1942). USOE, Castle. | 389 |

## Mechanics

| | Decimal classification |
|---|---|
| **Aerodynamics: air flow.** 18 min, (1943). USOE, Castle. | 533 |
| **Aerodynamics: forces acting on an air foil.** 27 min, (1941). USOE, Castle. | 533 |
| **Air in action.** 10 min, b&w or color, (1947). Coronet. (Wind tunnel demonstrations, chiefly for High School physics classes.) | 533 |
| **Analytical balance technique.** 30 min, si, (1941). United World Films. | 389 |
| **Application of Pascal's law: Parts I, II.** 12, 15 min, (1943). USN, Castle. | 532 |
| **Attitude gyro.** 18 min, (1945). Sperry. | 629.13 |
| **Basic hydraulics.** 10 min, color, (1944). Adel. | 532 |
| **Basic principles of lubrication.** 25 min, (1945). General Motors. | 621.89 |
| **Derivation of Pascal's law: Parts I, II.** 16, 18 min, (1943). USN, Castle. | 532 |
| **Diesel—the modern power.** 22 min, (1942). General Motors. | 621.4 |
| **Fluid flow in hydraulic systems.** 10 min, (1944). Adel. | 532 |
| **Gyro compass.** 10 min, (1943). Sperry. | 629.13 |
| **Gyroscope and the earth's rotation.** 10 min, (1944). USN, Castle. | 623.8 |
| **Gyroscope and gravitation.** 15 min, (1944). USN, Castle. | 623.8 |
| ***An introduction to vectors—coplanar concurrent forces.** 22 min, (1945). USOE, Castle. | 620.1 |
| ***An introduction to vectors—concurrent forces.** 22 min, (1945). USOE, Castle. | 620.1 |
| **Know your car.** 15 min, (1945). USOE, Castle. | 629.2 |
| **Principles of dry friction.** 17 min, (1945). USOE, Castle. | 531 |
| **Principles of lubrication.** 16 min, (1945). USOE, Castle. | 621.89 |
| **Principles of moments.** 23 min, (1945). USOE, Castle. | 531 |
| **Romance of the gyroscope.** 11 min, (1943). Sperry. | 629.13 |
| **Simple machines.** 11 min, (1942). Encyclopaedia Britannica Films. | 621 |
| **Smoke streams.** 30 min, si, (1941). Franklin Institute, Bray Studios. (43 scenes illustrating nature of flow around objects.) | 533 |
| **Sperry Gyrosyn compass.** 25 min, (1946). Sperry. | 629.13 |
| **Turning point.** 22 min, Castle. (Roller bearings and ball bearings.) | 621 |
| **V-1, the film of the robot bomb.** 9 min, (1945). British Information Services. | 940.542 |

## Heat

| | |
|---|---|
| **Aerology: ice formation on aircraft.** 48 min, (1944). USN, Castle. | 551.57 |
| **Aerology: thunderstorms.** 41 min, (1944). USN, Castle. | 551.5 |
| **Atmosphere and its circulation.** 11 min, (1945). Encyclopaedia Britannica Films. | 533 |
| **Clouds.** 11 min, (1939). USDA. | 551.57 |
| **Construction of Diesel Engines.** 17 min, (1945). USN, Castle. | 621.4 |
| ***Heat and its control.** 40 min, (1937). Johns-Manville. | 697 |
| **Heat and its control.** 20 min, (1938). USBM. (A shorter version of the preceding film.) | 697 |
| **Jet Propulsion.** 15 min, color, (1946). General Electric. | 532.525 |
| **Modern weather theory: primary circulation.** 19 min, (1940). AAF, Castle. | 551.5 |
| **Modern weather theory: development and characteristics of atmospheric waves.** 15 min, (1940). AAF, Castle. | 551.5 |
| **Molecular theory of matter.** 10 min. Encyclopaedia Britannica Films. | 541.2 |
| **Properties of refrigeration.** 20 min, (1945). Castle. | 621.5 |

| | Decimal classification |
|---|---|
| **Properties of water.** 11 min, (1941). Coronet. | 543 |
| **Radio frequency heating.** 40 min, color. Westinghouse. | 621.384 |
| **Thermodynamics.** 11 min, (1938). Encyclopaedia Britannica Films. | 536.7 |
| **Tornado in a box.** 28 min, (1946). Allis-Chalmers. (The gas turbine.) | 621 |
| **The weather.** 10 min, (1942). Encyclopaedia Britannica Films. | 551.5 |

## Sound

| | |
|---|---|
| ***Fundamentals of acoustics.** 10 min, (1933). Encyclopaedia Britannica Films. | 534 |
| **Musical instruments: the strings.** 10 min, (1947). Teaching Films. | 787 |
| **Sound.** 12 min, (1939). Edited Picture System. | 534 |
| **Sound recording and reproduction.** 10 min, (1943). Encyclopaedia Britannica Films. | 534 |
| ***Sound waves and their sources.** 10 min, (1933). Encyclopaedia Britannica Films. | 534 |

## Electricity and Magnetism

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|---|---|
| **Air waves.** 10 min, (1940). Ganz. (Radio broadcasting.) | 621.384 |
| **Capacitance.** 31 min, (1943). USN, Castle. | 621.31 |
| ***The cathode ray tube—how it works.** 15 min, (1943). USN, Castle. | 621.384 |
| **The diode.** 17 min, (1945). USOE, Castle. | 621.38 |
| **Electrical circuit faults.** 19 min, (1945). USOE, Castle. | 621.31 |
| **Electrochemistry.** 10 min, (1937). Encyclopaedia Britannica Films. | 541.37 |
| **Electrodynamics.** 10 min, (1936). Encyclopaedia Britannica Films. | 538 |
| **The electron—an introduction.** 16 min, USOE, Castle. | 541.2 |
| **Electronics at work.** 20 min, (1943). Westinghouse. (Six basic functions of electron tubes.) | 621.384 |
| **Elementary electricity—current and electromotive force.** 10 min, (1945). USN, Castle. | 537 |
| **Elementary electricity—amperes, volts, and ohms.** 8 min. USN, Castle. | 537 |
| **Elements of electrical circuits.** 11 min, (1943). Encyclopaedia Britannica Films. | 621.31 |
| **Magic in the air.** 9 min. General Motors. (Television.) | 621.388 |
| **Moving right along.** 15 min, (1947). American Telephone and Telegraph. | 621.388 |
| **On the air.** 28 min. Westinghouse. (Animated drawings showing technical side of broadcasting.) | 621.384 |
| **Primary cell.** 11 min, (1944). Encyclopaedia Britannica Films. | 621.35 |
| **Quality control.** 15 min, (1947). X-ray, Inc. | 539.26 |
| **Radio antennas: creation and behavior of radio waves.** 11 min, (1943). USN, Castle. | 621.384 |
| **Radio frequency heating.** 40 min, color. Westinghouse. | 621.384 |
| **Radio receivers: principles of radio receivers.** 17 min, (1945). USN, Castle. | 621.384 |
| **Receiving radio messages.** 11 min, (1943). Encyclopaedia Britannica Films. | 621.384 |
| **Röntgenstrahlen.** 20 min, (1937). Ufa Kulturfilm. (Commentary in German.) Museum of Modern Art. | 537.5 |
| **Rotating magnetic fields.** 13 min, (1945). USOE, Castle. | 621.31 |
| **Sending radio messages.** 10 min, (1943). Encyclopaedia Britannica Films. | 621.384 |
| **Series and parallel circuits.** 11 min, (1943). Encyclopaedia Britannica Films. | 621.31 |
| **Sightseeing at home.** 15 min, (1943). General Electric. (Television.) | 621.388 |
| **Single-phase and polyphase circuits.** 17 min, (1945). USOE, Castle. | 621.3 |
| **Story of FM.** 10 min, color, (1943). General Electric. | 621.384 |
| **Taking the x out of x-rays.** 7 min, (1946). General Electric. (Dr. W. D. Coolidge explains the x-ray tube.) | 537.5 |
| **Travelling electrical waves.** 50 min, si, (1936). MIT. (D.c. waves on open line, short-circuited, and loaded lines.) | 537 |
| ***The triode: amplification.** 14 min, (1945). USOE, Castle. | 621.38 |
| ***Vacuum tubes.** 11 min, (1943). Encyclopaedia Britannica Films. | 621.384 |
| ***Vacuum tubes: electron theory and the diode tube.** 16 min, (1945). Castle. | 621.384 |
| **What is electricity?** 20 min, (1944). Westinghouse. | 537 |
| **X-ray inspection.** 21 min, (1944). USOE, Castle. | 539.26 |

## Light

| | |
|---|---|
| **Alchemist in Hollywood.** 33 min, (1940). Solow. (Chemistry and physics of motion picture production.) | 771 |
| **Colour.** 15 min, color, (1948). British Information Services. | 535.6 |
| **Dawn of better living.** 15 min, color, (1946). Westinghouse. (Disney cartoons on lighting.) | 628.9 |
| **Eyes of science.** 45 min, si, (1930). Bausch & Lomb. | 681.4 |
| **How motion pictures move and talk.** 11 min, sd or si, (1939). United World Films. | 791.4 |
| **Introduction to optics.** 17 min, (1945). USN, Castle. | 535 |

| | Decimal classification |
|---|---|
| **Light control through polarization.** 22 min, color, (1946). Polaroid. | 535.5. |
| **Light is what you make it.** 10 min, color, (1946). National Better Light Better Sight Bureau. | 628.9 |
| **Light waves and their uses.** 10 min, (1937). Encyclopaedia Britannica Films. | 535 |
| **Magic of fluorescence.** 17 min, color, (1945). General Electric. | 621.3 |
| **Measurement with light waves.** 15 min, (1944). USOE, Castle. | 389 |
| ***The nature of color.** 10 min, color, (1947). Coronet. | 535.6 |

### Atomic and Nuclear Physics

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|---|---|
| **Atomic bomb test—Bikini Island.** 18 min, (1947). USN. | 909 |
| ***Atomic energy.** 16 min, (1947). Encyclopaedia Britannica Films. | 541.2 |
| ***Atomic physics.** 90 min, (1947). J. Arthur Rank Organization, Ltd. (Available, by purchase: United World Films; on loan, U. S. Atomic Energy Commission. Five parts: (1) The atomic theory; (2) Rays from atoms; (3) The nuclear structure of the atom; (4) Atom smashing: discovery of the neutron; (5) Uranium fission: nuclear energy.) | 541.2 |
| **Atomic power.** 19 min, (1946). March of Time. | 541.2 |
| **Operations crossroads.** 27 min, color, USN. (Two Bikini test explosions and preparations.) U. S. Navy. | 909 |
| **Paramount newsreel No. 99.** 25 min. Atomic Scientists of Chicago. (Hiroshima, Nagasaki, Bikini explosions.) | 909 |
| **Tale of two cities.** 20 min, 35 mm or 16 mm. U. S. Army. (Bombings of Hiroshima and Nagasaki.) | 909 |

### Biography

**D'Arsonval.** 20 min. Franco-American. (In French.)

**Louis de Broglie.** 20 min, 35 mm. Franco-American. (In French.)

**Langevin.** 25 min. Franco-American. (In French.)

### Distributors of the Films in this List

Adel Precision Products Corporation, 10777 VanOwen Ave., Burbank, Cal.

Allis-Chalmers Mfg. Company, Advertising and Public Relations Department, Milwaukee 1, Wis.

American Telephone & Telegraph Company, 208 W. Washington St., Chicago 6, Ill.

Atomic Scientists of Chicago, 1126 E. 59 St., Chicago 37, Ill.

Bray Studios Inc., 729 Seventh Ave., New York 19.

British Information Services, 30 Rockefeller Plaza, New York 20.

Castle Films Division, United World Films Inc., 1445 Park Ave., New York 29.

Coronet Instructional Films, Glenview, Ill.

Edited Picture System Inc., 165 W. 46 St., New York 19.

Encyclopaedia Britannica Films Inc., 1150 Wilmette Ave., Wilmette, Ill.

Franco-American Audio-Visual Distribution Center, Inc., 934 Fifth Avenue, New York 21.

Franklin Institute, Franklin School of Science & Arts, 251 S. 22 St., Philadelphia, Pa.

William J. Ganz, Institute of Visual Training, 40 E. 49 St., New York 17.

General Electric Co., Publicity Division, Visual Instruction Section, Schenectady, N. Y.

General Motors Corporation, 3044 W. Grand Blvd., Detroit 2, Mich.

Walter O. Gutlohn, 35 W. 45 St., New York.

March of Time Forum Edition, 369 Lexington Ave., New York 17.

Massachusetts Institute of Technology (Office of John J. Rowlands), 69 Massachusetts Ave., Cambridge 39, Mass.

Johns-Manville Sales Corporation, 1617 Pennsylvania Blvd., Philadelphia 3, Pa.

Modern Talking Picture Service Inc., 9 Rockefeller Plaza, New York 20.

Museum of Modern Art Film Library, 11 W. 53 St., New York 19.

National Better Light Better Sight Bureau, 420 Lexington Ave., New York 17.

The Polaroid Corporation, Cambridge 39, Mass.

Sidney Paul Solow, c/o Consolidated Film Industries, Hollywood, Cal.

Sperry Gyroscope, Great Neck, N. Y.

Teaching Films Inc., 2 W. 20 St., New York 11.

United World Films Inc., 445 Park Ave., New York 22.

U. S. Department of Agriculture, Motion Picture Service, Office of Information, Washington 25, D. C.

U. S. Navy, Motion Picture Section, Office of Public Information, Executive Office of the Secretary, Washington 25, D. C.

U. S. Atomic Energy Commission, Public Information Section, 1901 Constitution Ave., Washington, D. C.

U. S. Bureau of Mines Experiment Station, 4800 Forbes St., Pittsburgh 13, Pa.

Westinghouse Electric Corporation, 306 Fourth Ave., P.O. Box 1017, Pittsburgh 30, Pa.

X-ray Inc., 4525 12 St., Detroit, Mich.

# A Semantic Approach to the General Physics Laboratory

Andrew Longacre
*University of Illinois, Urbana, Illinois*

Every teacher knows the body of knowledge he is trying to infuse in his students and he is aware, at least intuitively, of the mental attitudes and activities required for adequate comprehension of the material of his course. Also he is aware of the value to himself and his course of any attempt to express in words these objectives of the teaching process. On the other hand, these objectives are only understood by the student through what should be called a learning process. Memorizing is the most common form of this but is scarcely adequate for physics. Any cognizance of the learning process as distinct from the teaching process is largely absent from physics teaching literature. While every course should be analyzed from such a point of view, this paper is concerned with an attack on the laboratory part of the general physics course.

The problem of how to make the laboratory an effective, worth-while part of a physics course is perennial. Laboratory work is a heritage from the time when natural philosophy, as physics used to be called, was the student's introduction to science and it was found that the student would better understand the subtleties of the exact analysis of a phenomenon if he could operate an apparatus himself while critically observing it. Physics is no longer the first course but it still seems reasonable to expect that the actual manipulation of apparatus should interest and benefit the student, especially when the mechanism of every device met in modern life is concealed by a "streamlined" cover. That the laboratory has not been a complete success seems evident from the number of local sets of instructions in the different institutions offering general physics, as well as from the back and forth shift between laboratory as an integral part of a main course and a separate laboratory course. An even greater manifestation is found in the variety of ways of conducting the laboratory. These range from the museum or push-button laboratory, through the instructionless laboratory where the student is told to find out something with a given apparatus, to the laboratory course where the student receives a printed instruction-data sheet on which he merely fills in the proper squares. There have also been several abandonments of laboratory altogether which have incensed the conservatism in each of us. But if the laboratory (1) does not definitely contribute to the understanding of the concepts being developed in the course, (2) does not provide the intellectual satisfaction of achievement, or (3) does not enhance a student's intellectual self-confidence, the less time spent on it the better. At least the time spent by the student in the laboratory should be reduced until the returns, evaluated in terms of the criteria just cited, are optimum. The alternative is further experimentation with the approach, content, and performance of the elementary physics laboratory.

In 1939 Weinberg[1] pointed out that semantics, variously defined as the science of meaning or the meaning of language, has pertinent application to a general physics course, because it leads to a study of the process of learning; in brief, "the natural order of understanding is descriptions before inferences and abstractions of low order before abstractions of high order." Beyond this stage, semantics becomes more detailed and points out that the acquisition of a body of knowledge in any field entails three steps. In the specific field of physics the novice must first "acquaint himself with the actual series of experiments that comprise the domain of physics to be learned." Second, "he must acquaint himself with relevant symbols or language and with some of the standard schemes for manipulating these." And finally, "he must be able to bridge the gap between the symbolism and the experimental facts which the symbols represent." The application of these semantic conclusions to each part of physics seems self-evident almost as soon as they are stated. They are more explicit than the caution with which an older master once admonished some young teachers—"Remember always that while the trained mind thinks from the general to the particular, the untrained mind thinks from the particular to the general."

An application of these principles and this

[1] Weinberg, *Am. J. Physics* **7**, 134 (1939).

order of learning has been consciously applied first to the laboratory of a general course at a prominent advanced preparatory school in New England[2] and then to the sophomore physics course at the University of Illinois. It led to instruction sheets and a procedure in the laboratory somewhat different from most, actually a sort of compromise of the extremes cited above. The results have been encouraging and it is the purpose of the rest of this paper to describe this application for what it is worth as it stands and for what it may suggest to others.

In order to provide motivation for the laboratory work it was recognized that all independent laboratory work stems from self-imposed questions. Occasionally one of them may be as prosaic as "Can I repeat these observations?" Still it is a question. This point is made in the section of the laboratory instructions entitled "Introduction to the Student" and is emphasized by initiating each part of each experiment with a question. To be sure, these are poor substitutes for self-imposed questions but they are better than either nothing or cold pragmatic statements of the "object" of the experiment. The student is urged to adopt each question as his own since a background in a subject is required before anyone can frame a question that is significant and feasible of experimental attack.

Examples of these are the questions for the experiment on Ohm's law. "I. Experimentally, what is the relation between the current through a conductor and the potential difference across the conductor? II. What is the resistance of each of the three conductors supplied?" It is only fair to point out that setting questions that both define the task and seem significant has not proven easy. Most of them have had to be revised, often several times, and there are still many that need further improvement.

The students have found that each motivating question essentially defines a finite task; that is, they know when an answer has been obtained and the job is done. Their perplexity as to just what is supposed to be sought and uncertainty as to the expected extent of the investigation, so frequently found, largely disappears. Instead there is the satisfaction and self-assurance that comes with accomplishment. This change of attitude in itself has seemed sufficient to warrant perpetuating this innovation.

Furthermore, the question usually implies just what data are appropriate for substantiating an answer. This correlation between a question and requirements for an answer is frequently pointed out in the early experiments. The instructions that are put in the students' hands leave theory to the textbook and directly attack the getting of suitable data. In the first question cited above "Experimentally, what is the relation between the current through a given conductor and the potential difference across it?" there is no mention of the fact that one will need a set of paired values of the current and corresponding potential difference. However, the student is required first to copy the leading question before taking any data. The act of writing it out serves to emphasize just what he is going to try to do. The instructions for Ohm's law start with the diagram of a suitable circuit consisting of a battery, potential divider, voltmeter, and ammeter. Mention is made that differing adjustments of the potential divider will give different voltages and hence different currents. The student is instructed to obtain a set of at least four pairs of values for each of two different conductors, since a single set will not be sufficient for any generalization.

In physics nearly every experiment brings a new apparatus. In this respect physics differs from chemistry and biology, to its disadvantage, since considerable time must be spent by the beginner at each session just learning to manipulate that apparatus before he can concentrate on the phenomena involved. Therefore, it seems appropriate to expedite getting at the real problem of the day by providing detailed manipulative instructions for each apparatus such as the set of instructions that comes with any device purchased. A novice *can* learn the intricacies of a movie camera without instructions, but only at a considerable waste of time and film. Industry respects his intelligence and his expression of confidence in buying its product by supplying instructions so that he can utilize the device immediately with a reasonable chance of obtaining acceptable results. The student who takes a course in physics expresses considerable con-

[2] Phillips Exeter Academy, Exeter, New Hampshire.

fidence in us and at the same time manfully admits there is something to be learned.

The instructions generally stop abruptly after the assembly of the raw data, and merely tell the student to "examine the data obtained and effect such calculations or draw such graphs as to substantiate an answer to the instigating question." This challenges the student at the point where he acknowledges he should be able to do the job and he respects the opportunity to "show his stuff." In the case of Ohm's law this means establishing proportionality with the data at hand. It may be done either by evaluating a ratio for each pair of data or by plotting a graph.

Another innovation is interspersing among the experiments articles on laboratory techniques that have general application. "The Establishment of Proportionality" is one of these. These general techniques are separately indexed and usually located just before the first experiment requiring them. Having them separated from the experiments leaves no doubt about the generality of their application. Spotting them among the experiments instead of in a long introductory section or chapter has several advantages. It definitely implies that not all of them are needed for the first experiment, wherein, actually, only one or two will be utilized. A complete barrage of these techniques is too much to assimilate at one time and the significance of many of them must be obscure to a novice. Finally, coming upon a new one every so often serves to remind the student of the others. There are eighteen of these techniques on such topics as "Recording Data by Labeled Items," "Weighing with Trip Scales," "Recording Data by Labeled Diagrams," "Calculations," "Introduction to Significant Figures," "Drawing Graphs of Experimental Data," "Use of Electrical Equipment," "Wheatstone's Bridge," "Optical Diagrams."

The reports required of the student have also been simplified and reduced to the three most significant features, (1) the record of the data and calculations, (2) a summary of the procedure, and (3) answers to the leading questions and other pertinent conclusions.

The record of the data is generally made in pencil and the student is frankly told that accuracy in the record and orderliness in calculations are more important than neatness. However, if the original record gets too messy, it is to be copied and both copies kept as part of the report. Throughout, emphasis is placed on such fundamentally good practices as recording numbers precisely as read, always noting units, orderly substitution in the appropriate formulas, and always clearly indicating the calculation performed.

The summary of the procedure should, ideally, be a succinct report, of a few sentences at most, noting the salient features of the procedure used. It is stated in the introduction that the summary should constitute the answer to a respected friend who has asked the question, "How did you prove Ohm's law?" for example. Under such circumstances, one wants to be brief and direct and mention only the principal arrangements and those points that distinguish this procedure from any other that might have been used. To do so in a sentence or two is an art that becomes an educated man, especially after he has spent from one to three hours on the experiment. As a rule a student's first attempts are pretty bad, ranging from "With the circuit shown we proved Ohm's law" to a lengthy, muddled set of instructions. Generally, the students accept the challenge, see its value, and before long produce very satisfactory, orderly, forthright summaries. A teacher becomes acutely aware of this when he starts the next group of beginners. The student seems to feel that such a report is more significant than an immature dissertation or a set of instructions copied from one that already exists.

It is required that the answers to the leading questions be complete, self-contained statements, and that each must be accompanied by a brief statement as to how the data substantiate the answer. More often than not in getting the answer to the question several other facts of physics are established, of which a fair portion with corresponding substantiating statements are also required to be recorded. Good students occasionally make unforeseen inferences and offer valid substantiations. Under such circumstances extra credit is merited and assigned, provided the rest of the report warrants it.

In planning the instruction sheets it was decided to have each experiment embrace one particular phenomenon. This policy demanded

several unusually short experiments. The experiment on "Ohm's law" is one of these and its sequel, "Combinations of Resistances," is another. Since they both require the same circuit, both are assigned for one session. Separating them seems to help the student to keep clearly in mind just what he is doing. With laboratory notebooks a new experiment starts on a fresh page; with looseleaf report sheets each experiment has its own set of pages.

Occasionally it is found that the material connected with one phenomenon is more than sufficient for a single meeting. With small classes and plenty of room it is possible to continue at the next session. More often the classes are large, from 15 to 30, and several classes use the same space in successive hours. This simply means that what is to be done must be done in one session. Two ways have been found to handle this situation. For the type of experiment where repetition is desired in order to establish a generalized answer, it is feasible to have different teams use different operating conditions, and then to have each team utilize data from other teams. An example of this is found in copper plating wherein it just takes too long to put down and weigh a deposit to permit repeating it for different currents and times. On the other hand, many long experiments are logically broken up into parts and an appropriate number of these may be assigned for an afternoon's work. If there are several unassigned parts in the instructions, the student realizes that more varied experiments are needed for an adequate investigation of the phenomenon than he has time to do.

Thus by means of several devices the student's job in the laboratory is made definite and fruitful. Leading questions establish finite tasks with recognizable termini. Detailed manipulative instructions recognize the novelty of each apparatus and permit the efficient use of the student's time in the taking of adequate data. The reduction of the data and the extension from the particular case to generalized conclusions are suitable work for any mature individual and are not "busy work."

It has been found that the manner of handling the experiments, just outlined, has aided materially in avoiding or correcting some of the common semantic blunders listed by Weinberg.[1] The first of these is the "confusion of inferences and descriptions." Confusion is avoided by omitting any discussion of general principles and concentrating on concrete data. The summary of procedure is primarily a succinct description. It is only after the data have been collected that any inferences are called for and considered. There is no previous discussion of general principles. The second common blunder is the "substitution of facility in the use of symbols for understanding of structural similarity." The sharp division that is made between assistance from the instruction sheet in obtaining data and putting the student on his own when it comes to the reduction of the data tends to prevent this blunder. The third common pitfall is "the use of symbols whose structure does not correspond to that of the physical referent." With minute instructions directing the taking of the data there can be little doubt that the referent has been made common for all members of the class. It then becomes merely a question of the student understanding what he saw. There should be no misunderstanding of what constitutes the referent.

Actually, laboratory work has *always* assisted in surmounting the three steps of the learning process as well as in avoiding the specific blunders emphasized by semantics. Here is displayed the weakness as well as the strength of semantics: It says what every teacher has known intuitively right along. However, in planning our laboratory work, reliance on the intuitive was minimized and the approach to, and the conduct of, the laboratory course described was worked out with the statements of both the semantic steps of the learning process and semantic blunders written out. So far the experience with this approach has been that the students develop a healthy, virile attitude toward both the experiments and the soundness of conclusions. This is the goal that has been consciously sought, even occasionally by what some people might refer to as "low means." An example of this, appropriate for a preparatory school, is the first experiment on specific gravity which simply asks the student to evaluate the specific gravity of the block of wood used in previous experiments for initial exercises in linear measurements and weighing.

It is pointed out that the definition of specific gravity calls for the weight of an object and the weight of an equal volume of water, and that only the latter item needs to be obtained, the volume of the block having been evaluated earlier. It is suggested that the weight of an equal volume of water *may* be obtained by measuring out the right amount of water with a graduate and weighing it in a beaker. Only one out of several hundred students came and said that he knew there was no need to do that since he knew the density of water. The rest went ahead and carefully measured out the required 267 cubic centimeters or whatever was appropriate and after weighing the beaker with and without the water obtained a weight of 267 grams. This was followed universally first by disgust and then by a determination not to be duped into such a job again. In ten minutes they had relearned that the density of water is 1.00 g/cm$^3$ the hard way. But in those ten minutes they had learned more. If it had taken longer, none of us would have practiced such chicanery because the students would have justly resented it rather than have become disgusted with themselves. Now, they were on the way to "ride the course" and become masters of it to the best of their abilities.

## A Demonstration Thermal Diffusion Column

B. B. McIntEER AND C. E. SCHENSTED
*University of Minnesota,* Minneapolis 14, Minnesota*

IN the course of recent work on the separation of helium isotopes by hot wire thermal diffusion columns[1] it was observed that the presence of air, or other heavy impurities which separate from the helium, causes serious local heating of the wire at the lower end of the column due to the small thermal conductivity of these gases as compared with helium. A glass demonstration thermal diffusion column has been constructed in which the effect can readily be seen. In operation, the column is filled with a mixture of helium and air. The subsequent separation of the two gases is indicated by the wire becoming brighter at the bottom of the column than at the top. The effect is so pronounced that a current through the wire producing incandescence in air is insufficient to produce a visible glow where the wire is surrounded by helium.

The column was constructed of 127 cm of 8 mm I.D. Pyrex tubing. Two cm from each end the glass was collapsed with the result that a direct metal to glass seal was made to the 0.10-mm platinum heater wire which extended the length of the column as shown in Fig. 1. Because of the expansion of the heater wire it is necessary to maintain a slight tension in order to keep the wire in alignment with the axis of the tubing. This is accomplished by sealing a 1 g weight of telescoping glass tubing to the wire about 5 cm above its lower end, as shown. A gas entrance tube sealed near the top completes the column.

The direct sealing of Pyrex glass to the platinum might possibly result in slight leakage (although this was not observed in the writers' column); however, this is of little consequence

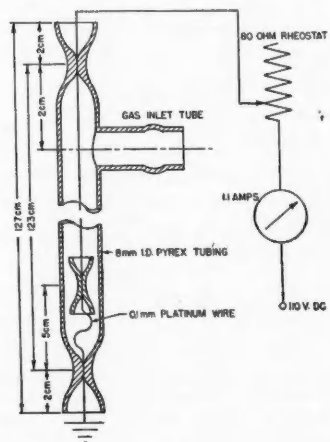


FIG. 1. Details of thermal diffusion column construction.

* Assisted by the joint program of the ONR and the AEC.

[1] B. B. McInteer, L. T. Aldrich and Alfred O. Nier, *Physical Rev.* **74**, 946 (1948).

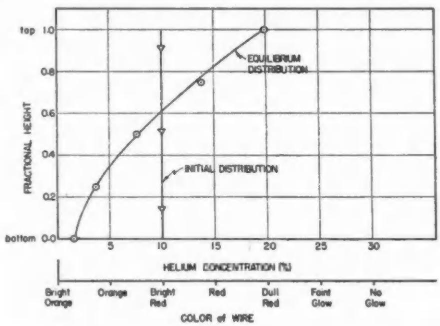


FIG. 2. Performance of demonstration column when filled initially to atmospheric pressure with 10 percent helium-air mixture.

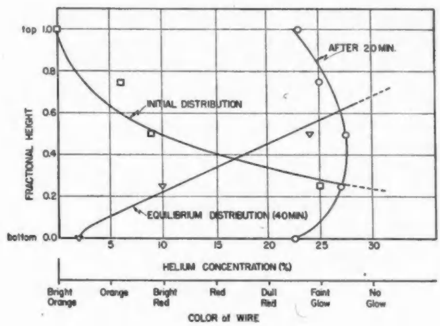


FIG. 3. Performance of demonstration column when filled to 0.25 atmos. with helium, with air added to atmospheric pressure.

since the device was designed for use at atmospheric pressure. The external glowing lengths of wire offer a standard for comparison. In turning on the column, the voltage on the wire is increased slowly; if this is not done, hot spots develop along the wire which may result in burning out. At the maximum operating voltage, 80 v d.c., the current was 1.1 amp. Alternating current was not used because induced vibrations would result from action with the earth's magnetic field.

Figures 2 and 3 present graphically the behavior of the column under two different operating conditions. In the run shown in Fig. 2 the column was initially filled with a uniform 10 percent helium–90 percent air mixture. At the end of 20 minutes the equilibrium distribution shown in the figure was reached. In order to measure the concentrations a second column was constructed having a cross section identical to the separating column, but being only 15 cm long. This was permanently filled with air. By adjusting the voltage across this column the wire brightness could be made to correspond to that of any point along the separating column. A calibration of this voltage was made by filling the separating column with known mixtures of air and helium and obtaining a photometric balance before significant separation had taken place.

Figure 3 shows the results obtained if one initially admits a slight amount of pure helium and adds air up to atmospheric pressure, thus producing a distribution which is the inverse of that which is obtained at equilibrium. At an intermediate time of approximately 20 minutes a nearly uniform distribution occurs, with equilibrium being reached after 40 minutes.

Although a column of this design should be equally effective with hydrogen, care must be taken in view of the explosion hazard of hydrogen-oxygen mixtures in contact with hot platinum. It would seem that use of hydrogen-nitrogen mixtures might be a safe modification, if helium is not available. W. M. Spicer[2] has previously described a demonstration column using bromine-air mixtures. Its size and time of operation are, however, much greater than those of this new type of column.

We wish to express our appreciation to Professor Alfred O. Nier for his interest and encouragement in this work.

[2] W. M. Spicer, J. Chem. Ed. **22**, 593 (1945).

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*Man Thinking; him Nature solicits with all her placid, all her monitory pictures; him the past instructs; him the future invites. Is not indeed every man a student, and do not all things exist for the student's behoof? And, finally, is not the true scholar the only true master? But the old oracle said, 'All things have two handles: beware of the wrong one.'*—EMERSON, *The American Scholar.*

# Diffraction of Light by Two Noncoplanar Parallel Straight Edges

JAMES R. HEIRTZLER*
*Louisiana State University, Baton Rouge, Louisiana*

IN a recent issue of this journal C. F. Ellis published an article on diffraction of light by two noncoplanar obstacles.[1] As obstacles he used a disk and a straight edge and noted a bulging of the diffraction patterns toward the obstacle nearer the light source. He explained this bulging as due to a relative shift in the "geometrical" and "optical" centers of the patterns. The geometrical center was defined as the point midway between the limits of the geometrical boundaries and the optical center as the position of the central fringe. He determined the shift in the geometrical center by elementary calculations and the shift in the optical center by considering a modified form of Young's experiment. He admitted that this method of finding the optical center was not a rigorous one.

A more exact method of determining the diffraction pattern theoretically can be employed if we use two straight edges as the obstacles. To such a problem as this the Kirchhoff diffraction formula can be applied to determine the intensity of illumination as a function of distance along some plane of observation.

### Theory

Drude[2] has applied the Kirchhoff formula to a slit, which is effectively two coplanar straight edges. By following his procedure, and making those generalizations which arise from the fact that the edges are not coplanar, we can arrive at a similar expression for the intensity.

It is first necessary to fix the configuration of the system so that the opening lies between the source $Q$ and the point of observation $P$ (see Fig. 1). The origin is located on the surface of the opening with the planes of the edges, the $xy$ plane, and the plane through the point of observation all parallel. The projection of the line $QP$ on the $xy$ plane coincides with the $x$ axis and $Q'$, the projection of $Q$ on the $xy$ plane, is located midway between the two edges, which have coordinates $x'$ and $x''$. The expression for the intensity is then found to be

$$J=\frac{A}{2(\rho_0+\rho_1)^2}\left\{\left(\int_{v''}^{v'}\cos\frac{\pi v^2}{2}dv\right)^2+\left(\int_{v''}^{v'}\sin\frac{\pi v^2}{2}dv\right)^2\right\} \quad (1)$$

with $A$ = constant,

$$v'=x'\cos\varphi\left[\frac{2}{\lambda}\left(\frac{1}{\rho_0}+\frac{1}{\rho_1}\right)\right]^{\frac{1}{2}}E, \quad (2)$$

$$v''=x''\cos\varphi\left[\frac{2}{\lambda}\left(\frac{1}{\rho_0}+\frac{1}{\rho_1}\right)\right]^{\frac{1}{2}}E, \quad (3)$$

$\lambda$ = wavelength of light, and

$$E=1-\frac{d\tan\varphi}{\delta}.$$

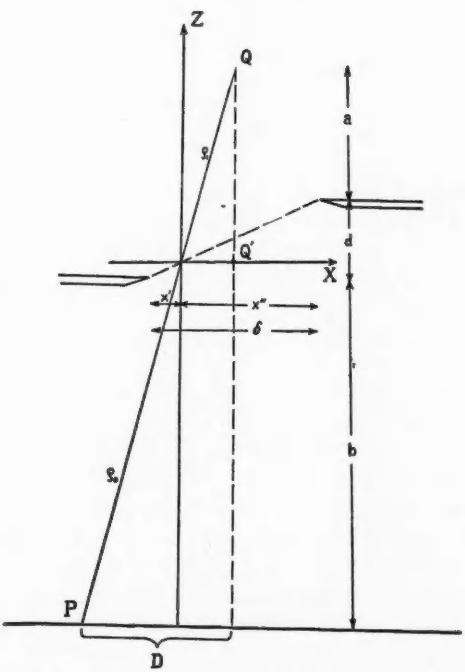


FIG. 1. Arrangement of source, straight edges, and plane of observation.

* Now at Department of Physics, New York University, New York, New York.

[1] Ellis, *Am. J. Physics* **16**, 8–13 (1948).

[2] Drude, *Theory of optics* (Longmans, Green, and Co.), pp. 185–201.

The significance of the symbols $\rho_0$, $\rho_1$, $a$, $d$ and $\delta$ is evident from Fig. 1; $\varphi$ is the angle $\rho_1$ makes with the $z$ axis.

Equations (1), (2) and (3) are the same as Drude's except for the factor $E$ of Eqs. (2) and (3). When $d$ becomes zero the factor $E$ becomes 1.

It is seen that Eq. (1) is in terms of Fresnel integrals and, therefore, can be evaluated by the Cornu spiral. Equations (2) and (3) do not give $v'$ and $v''$ in a usable form so it is necessary to express Eqs. (2) and (3) in terms of the parameters of the system, namely $a$, $d$, $b$ and $\delta$. Doing this, and retaining only first-order terms in expressions involving small quantities, we obtain

$$v'=\left(\frac{\delta}{2}-\frac{F\delta}{d}\right)\left(\frac{2}{\lambda}G\right)^{\frac{1}{2}}\left(1-\frac{FG}{2}\right), \tag{4}$$

$$v''=\left(-\frac{\delta}{2}-\frac{F\delta}{d}\right)\left(\frac{2}{\lambda}G\right)^{\frac{1}{2}}\left(1-\frac{FG}{2}\right), \tag{5}$$

where

$$F=\frac{Dd(a+d/2)}{Dd+\delta(a+d+b)}$$

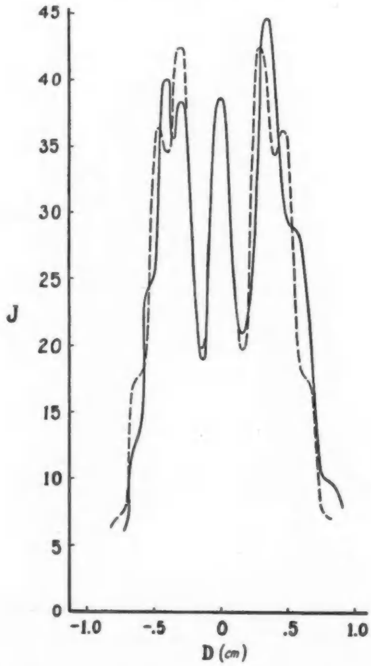


Fig. 2. Coplanar and noncoplanar straight edges. For the broken line $d=0$, $\delta=0.48$ cm; for the solid line $d=120$ cm, $\delta=0.48$ cm.

and

$$G=\frac{1}{a+d/2}+\frac{1}{b+d/2}.$$

The above values of $v'$ and $v''$ were applied to a spiral constructed to the size of $22\times22$ inches and about 15 different curves of $J$ *vs.* $D$ were plotted. Figure 2 shows such a curve for noncoplanar edges, with a coplanar for comparison. The distances $a+d/2$ and $b+d/2$ are kept constant at 6.0 m and 13.6 m, respectively, in all of the figures shown. The dissymmetry introduced by having the straight edges in different planes is clearly visible.

### Experimental Procedure

In order to compare the derived formula with experimental data some photographs were taken of diffraction patterns, and from the negatives of these photographs recordings of $J$ *vs.* $D$ were made on a recording microphotometer.

For the most part the apparatus used was the same as that used by Ellis. The same light source (a mercury arc) and pinholes were used, and a Wratten light filter No. 77 was placed beyond the second pinhole to isolate the 5461A line of the mercury spectrum. Two jointer knives were used as straight edges. These knives were clamped to the edges of two $5\times6$ in. pieces of black plastic to increase their effective widths, and the exposed parts of the knives were blackened with India ink. The pieces of plastic were then mounted on a two-meter optical bench in such a manner as to provide longitudinal and transverse movement of the edges.

Each of the edges was separately aligned by the use of a transit telescope mounted in the place of the film, and each edge backed off half the distance of $\delta$. Kodak Contrast Process Ortho $4\times5$ in. film was used and exposures made for 20 minutes.

Scratches were made on the negative to indicate the scale of $D$ after the recording was made. A Leeds and Northrup recording microphotometer was used and some of the recorded curves are shown in Figs. 3 and 4. The broken line shows the theoretical curve to the same scale.

### Discussion

At several points in the theoretical and experimental procedures errors could have been intro-

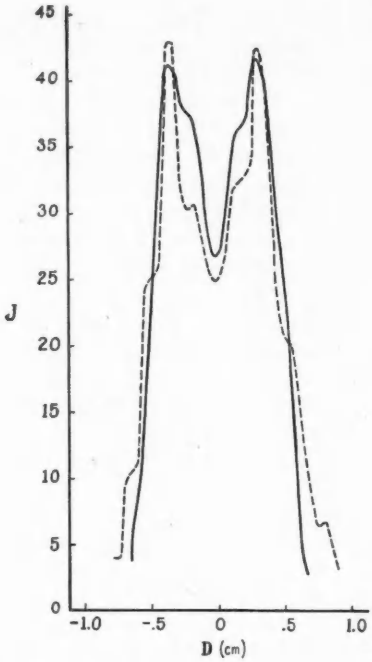


FIG. 3. Experimental curve of light intensity (solid line), with corresponding theoretical curve (broken line), for $d=40$ cm and $\delta=0.44$ cm.

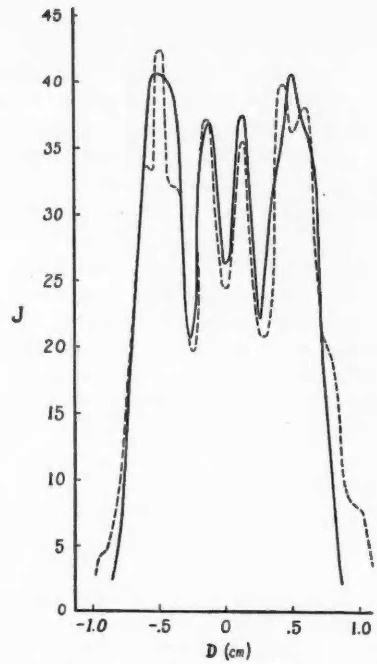


FIG. 4. Experimental curve of light intensity (solid line), with corresponding theoretical curve (broken line), for $d=80$ cm and $\delta=0.56$ cm.

duced. As stated before, approximations had to be made in deriving Eqs. (1), (4) and (5). Numerical values were substituted in the exact and approximate expressions each time an approximation occurred. Under the assumption that the Kirchhoff formula is correct,[3] the above errors, and the small error in taking readings from the spiral, make the theoretical curves not more than 5 percent in error. The smaller the values of $d$, $\delta$ and $D$, the less the error.

The errors introduced in the experimental procedure are due to two causes: The first is the error in setting the value of $\delta$ on the optical bench. For the matched curves it was found that the value of $\delta$ needed for the theoretical curve was from 0.04 to 0.08 cm larger than the value of $\delta$ as originally measured in setting the edges. This error can be attributed to the setting of the edges because this error also existed in curves for the coplanar case. In the coplanar case our expression for the intensity is the same as the well-known Drude expression. All of the adjustments that had to be made in the value of $\delta$ were of the same order of magnitude as for the coplanar case. The other error is inherent in the recording of intensities with the microphotometer; this latter error flattens the peaks of the experimental curves.

The most notable feature of the theoretical diffraction patterns is the increase in dissymmetry as $d$ is increased. Furthermore, it will be noted that the variations in intensity with $D$ can be divided into *strong* fringes and *weak* fringes, with the weak fringes superimposed on the more intense strong fringes. When $d$ increases and $\delta$ remains constant the strong fringes seem to remain unchanged but the weak fringes move toward more positive values of $D$. The values of intensity at $D=0$ remains the same as it was for the coplanar case. When $\delta$ increases and $d$ re-

[3] Mitra (*Phil. Mag.* **37**, 50 (1919)) has pointed out that the Kirchhoff formula leads to incorrect results for large angles of diffraction. It is to be noted that here, even though the plane of our opening makes a very acute angle with the light ray, our angles of diffraction are small.

mains constant the strong fringes are modified in such a way as to add one new peak for approximately 0.1 cm increase in $\delta$. The weak fringes move in toward the zero value of $D$.

Altogether five experimental curves were recorded and matched to theoretical curves. Each of the theoretical curves that was matched to an experimental curve was found by plotting a series of curves with consecutive values of $\delta$ and choosing the curve that matched best. These consecutive values of $\delta$ differed by no less than 0.01 cm, so some intermediate value may have matched more closely. Also it is to be noted that stress was laid on matching the strong fringes, and, as a result, some mismatch occurs in the weak fringes.

On the curves the central fringe seems always to occur at $D=0$. Actually the shift of this optical center is not zero, but is very small, and can be found if Eq. (1) is developed as a function of small values of $D$. The only important shift is that of the geometrical center. These results are in agreement with Ellis' findings.[4] With the values of the parameters of the system that he used (which are practically the same as the ones used here), it follows from his expression that the shift in the optical center is approximately one percent of the shift in the geometrical center. This accounts for the fact that no shift of the central fringe can be observed on the theoretical curves.

This investigation was made as partial fulfillment of the requirements for the degree of Master of Science at Louisiana State University. The author would like to express his appreciation to Dr. George Jaffé for his guidance and assistance.

[4] It should be mentioned, however, that the shift in the optical center comes out proportional to the wave-length $\lambda$, not independent of $\lambda$ as in Ellis' simplified treatment.

# Optical Methods for the Determination of Flame Temperatures
# I. Two-Color and Line-Reversal Techniques*

S. S. Penner
*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California*

## 1. Introduction

THE measurement of flame temperatures is of considerable practical importance in connection with the development of internal combustion engines, turbines, ramjets, rockets, etc. Knowledge of the flame temperature provides a direct indication of the degree of completion reached by the chemical reactions in the combustion chamber. Flame temperature measurements are therefore a measure of combustion efficiency and over-all performance. This statement is illustrated by the fact that it is possible to obtain flame temperatures, under optimum operating conditions, which are in reasonably good agreement with results calculated on the assumption that thermodynamic equilibrium is reached in the combustion chamber.

Experiments to determine the flame temperatures of gases were made in 1817 by Davy[1] who exploded a mixture of cyanogen and oxygen and calculated the temperature from the observed increase in volume. Similar experiments were carried out by Bunsen half a century later. Fairly complete references to the first published work on temperature determinations are given in a paper published by Becquerel[2] in 1863. Optical methods for the measurement of flame temperatures were considered by Rosetti[3] some years later. Most of the modern techniques for temperature determinations such as the thermocouple method,[4–6] the line-reversal technique,[7] and the compensated hot-wire method[8] were

* This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under U.S. Army Ordnance Department Contract No. W-04-200-ORD-1482.

[1] Davy, *Phil. Trans.* 67 (1817).
[2] M. E. Becquerel, *Ann. de Chim. et Physique* (3), **68**, 49 (1863).
[3] F. Rosetti, *Ann. de Chim. et Physique* (5), **18**, 457 (1879).
[4] E. J. Waggener, *Ann. der Physik* **58**, 579 (1896).
[5] E. L. Nichols, *Physical Rev.* **10**, 234 (1900).
[6] G. W. Stewart, *Physical Rev.* **13**, 257 (1901).
[7] Ch. Féry, *Comptes Rendus* **137**, 909 (1903).
[8] H. Schmidt, *Ann. der Physik* **29**, 971 (1909).

introduced near the turn of the last century.

The determination of flame temperatures by the use of thermocouples,[4–6, 9] resistance thermometers,[10] metallic or ceramic probes,[11, 12] offers considerable experimental difficulties and may not be feasible at all if the flame temperatures are excessively high. Optical methods possess the unique advantage of permitting temperature measurements without disturbing the combustion process. However, it is usually not possible to make a point by point temperature exploration of the flame zone by the use of an optical method.

The advantages of the determination of flame temperatures by optical procedures have been recognized for a long time. It is therefore not surprising to find that considerable effort has been expended by a large number of investigators over a period of many years on the development and improvement of optical techniques for the determination of flame temperatures. The achievements of these studies have been elaborated periodically in a number of review papers by the leading authorities in this field. For this reason no attempt will be made in the following discussion to give a description of the experimental problems involved in the application of any one of the optical procedures. Instead, efforts will be directed toward providing a critical review of the principles involved in the measurement of flame temperatures by various optical means and to indicate under what conditions a given set of temperature measurements may be expected to yield significant results. For a review of the fundamental empirical and theoretical relations which form the basis of heat transfer and radiation calculations employed in this summary article, the reader is referred to the published literature.[13–17] For an interesting survey of a number of methods involving quantitative studies of emission spectra for the determination of stellar temperatures, reference should be made to a recent article by Petrie.[18]

Before proceeding with the discussion of flame temperature measurements by various optical techniques it appears desirable to consider the meaning of temperature in a nonequilibrium system such as a combustion flame.[19] From the operational point of view, there are as many different temperatures as there are methods for measuring temperature. Thus, we may speak of a rotational temperature determined from a variation in intensity of the emitted radiation with rotational quantum number and obtain different numerical results for each molecular species selected for measurement; we may speak of a temperature defined through the temperature of line-reversal of a given spectral line such as one of the lines of the well-known doublet of sodium; we may speak of a thermocouple temperature measured by the use of a balancing circuit and a bimetallic element and obtain results strongly dependent on the choice of thermocouple material. It is apparent that none or all of these definitions of temperature may be significant depending upon their agreement with one another and with a criterion which is known to be useful for indicating combustion efficiency.

Experience has shown that the numerical values of temperature determined by a given set of measurements approach, but never exceed, the thermodynamic equilibrium temperature even in nonequilibrium systems, provided the method whereby the temperature is determined involves measurements on quantities which are in statistical equilibrium with the random translational energy distribution of the molecules. We may, therefore, regard a value of the temperature determined under conditions of statistical equilibrium as a direct measure of combustion efficiency. In practice it may prove to be exceedingly difficult to eliminate all instances of abnormal excitation which would lead to erroneous results. For this reason it is preferable to make temperature determinations by several independent methods rather than to assume that

[9] *Temperature, its measurement and control in science and industry* (American Institute of Physics, Reinhold Publishing Corp., New York, 1941), p. 775.

[10] W. P. Wood and J. M. Cork, *Pyrometry* (McGraw-Hill Book Co, Inc., New York, 1941), Chap. IV.

[11] G. E. Zima, *Jet Propulsion Laboratory Progress Report 9–18*, March, 1947.

[12] J. A. Curcio and D. V. Estes, *Project Squid, Technical Memorandum NYU-2* April, 1948).

[13] H. T. Wensel, Ref. 9, p. 3.

[14] M. Born, *Optik* (J. Springer, Berlin, 1933).

[15] W. H. McAdams, *Heat transmission*, Chapter III by H. C. Hottel (McGraw-Hill Book Co., Inc., New York, 1942).

[16] W. E. Forsythe, *Measurement of radiant energy* (McGraw-Hill Book Co., Inc., New York, 1937).

[17] M. Planck, *Vorlesungen über die Theorie der Wärmestrahlung* (J. A. Barth, Leipzig, 1921).

[18] W. Petrie, *Am. J. Physics* **16**, 378 (1948).

[19] The following discussion is taken from the author's article, "Radiation from rocket flames and its effect on rocket performance," *Am. J. Physics* **16**, 475 (1948).

any one procedure will lead to a significant value for the flame temperature. If two or more independent experimental techniques lead to the same numerical result for the flame temperature in nonequilibrium systems, then it appears very likely that the true flame temperature (defined through the random translational speed of the gas molecules) has been measured.

## 2. The Two-Color Technique for Measuring Flame Temperatures

*A. Historical Introduction.*—The two-color technique for measuring flame temperatures is based on principles which have been understood for nearly half a century. Morris, Stroude, and Ellis assumed in 1907 that two different incandescent lamps were at the same temperature when their colors were the same.[20] An early discussion of the radiation laws with reference to brightness temperatures and greybodies has been given by Hyde.[21] The dependence of color temperature on wavelength and the theoretical bases for the two-color technique for measuring flame temperatures were indicated in an article written by Hyde, Cady, and Forsythe in 1917.[22] Extensive practical applications of the two-color technique have been made in recent years. Russell, Lucks, and Turnbull[23] described a two-color optical pyrometer in 1941. Kracek and Benedict used the two-color method for the measurement of flame temperatures in closed chambers and in guns during the early years of the Second World War.[24] Craig subsequently extended the work of Kracek and Benedict to flame temperature measurements on solid fuel rocket motors.[24] German investigators have also employed the two-color technique for temperature measurements on rockets, particularly, for exploration of the temperature history along the exhaust jets of liquid-fuel motors.[25] Almost simultaneously with the German and American war-born applications of the two-color technique to studies on rockets, a group of investigators at the University of Wisconsin[26] initiated measurements on internal combustion engines by using earlier emissivity measurements of carbon flames obtained by Hottel and Broughton.[27] More recent discussions of the two-color technique have been given by Jacobs and Scholnick.[28]

*B. Outline of Theory.*—The two-color technique for the measurement of flame temperatures requires experimental determination of the radiant intensities emitted from a given flame in two well-defined wavelength regions. The measured radiant intensities define two brightness temperatures and a color temperature. The two brightness temperatures are the same and the flame temperature is equal to the color temperature if the emissivities of the flame are identical for the two chosen wavelength regions.[24] If the emissivities for the two wavelength regions are not equal, then the true flame temperature can be calculated from the observed color temperature by the use of independently determined emissivity data.[26,27] These summary statements concerning the determination of flame temperatures by use of the two-color technique will now be described quantitatively with the aid of the radiation laws and the definitions of color and brightness temperatures.

The rate of emission of radiant energy from a blackbody is given by the well-known relation derived by Planck in 1900. For sufficiently small values of the product of wavelength and temperature, Wien's equation[29] for the radiant intensity is applicable as a very close approximation, i.e.,

$$J(\lambda, T)d\lambda = (c_1/\lambda^5)\exp(-c_2/\lambda T)d\lambda, \quad (1)$$

where $J(\lambda, T)d\lambda$ is the radiant intensity in ergs/(cm$^3$ sec) emitted by unit area of a blackbody radiator over a solid angle of $2\pi$-steradians at the temperature $T$ in the wavelength region

[20] J. T. Morris, F. Stroude, and R. M. Ellis, *The Electrician* **59**, 584 (1907).

[21] E. P. Hyde, *J. Franklin Inst.* **169**, 439 (1910); *ibid.* **170**, 26 (1910); *Trans. Soc. Illum. Eng.* **4**, 334 (1909); *Astrophysical J.* **36**, 89 (1912).

[22] E. P. Hyde, F. E. Cady, and W. E. Forsythe, *Physical Rev.* **10**, 395 (1917).

[23] Ref. 9, p. 1159.

[24] Cf., *Am. J. Physics* **16**, 475 (1948).

[25] H. Frieser and R. Reuther, Archiv. No. 38/1gk, translated by H. A. Liebhafsky, General Electric Co., Schenectady, New York, February 1947.

[26] O. A. Uyehara, P. S. Myers, K. M. Watson, and L. A. Wilson, *Trans. Am. Soc. Mech. Eng.* **68**, 17 (1946).

[27] H. C. Hottel and F. P. Broughton, *Ind. Eng. Chem., Anal. Ed.* **4**, 166 (1932).

[28] D. H. Jacobs and S. Scholnick, North American Aviation Co., Inc., Report No. 86, January 1947.

[29] Planck's equation reduces to Wien's equation if $\exp(c_2/\lambda T) \gg 1$. This condition is adequately fulfilled for all wavelengths less than about $1\mu$ if the temperature is 3000°K or less.

between $\lambda$ and $\lambda+d\lambda$, $c_1=3.74\times10^{-5}$ (erg cm$^2$)/sec, and $c_2=1.432$ cm °K.

The spectral emissivity $\epsilon(\lambda, T)$ is defined as the ratio of the radiation intensity emitted by a given substance to the radiation intensity emitted by a blackbody at the same temperature. The color temperature $T_c$ of an emitter is defined as the temperature at which a blackbody emits radiation having the same ratio of radiant intensities at the wavelengths $\lambda_1$ and $\lambda_2$ as the emitter under study. This definition of $T_c$ can be expressed analytically by the relation

$$\frac{J(\lambda_1, T_c)}{J(\lambda_2, T_c)}=\frac{\epsilon_1(\lambda_1, T)J(\lambda_1, T)}{\epsilon_2(\lambda_2, T)J(\lambda_2, T)}. \tag{2}$$

Combining Eqs. (1) and (2) leads to the following relation between color temperature $T_c$ and true temperature $T$:

$$(1/T)-(1/T_c)=\ln(\epsilon_1/\epsilon_2)/c_2[(1/\lambda_1)-(1/\lambda_2)]. \tag{3}$$

It is evident from Eq. (3) that the color temperature will be equal to the true temperature, independent of the choice of the arbitrary wavelengths $\lambda_1$ and $\lambda_2$, if the substance under study is a blackbody ($\epsilon_1=\epsilon_2=1$) or a greybody ($\epsilon_1=\epsilon_2<1$).[30] If the substance under study is not a greybody, then the true flame temperature can still be determined from the observed color temperature provided the dependence of emissivity on wavelength is known.[26,27]

For the sake of completeness it appears desirable to point out that it is not necessary to determine the radiant intensity at two wavelengths when the emissivity is known since in this case the flame temperature can be calculated from the brightness temperature directly. This follows since the spectral brightness temperature is defined as the temperature $T_{br}$ at which a blackbody would emit radiation in the chosen spectral range of the same intensity as that emitted by the source under study, i.e.,

$$J(\lambda, T_{br})=\epsilon(\lambda, T)J(\lambda, T). \tag{4}$$

If the intensity of radiation from a blackbody is adequately represented by Wien's equation, then it is evident from Eq. (4) that the relation between the true temperature $T$ and the brightness temperature $T_{br}$ is

$$1/T-1/T_{br}=(\lambda/c_2)\ln\epsilon_\lambda, \tag{5}$$

whence the true temperature $T$ can be determined if $\epsilon_\lambda$ is known.

*C. The Two-Color Technique.*—The two-color technique for measuring flame temperatures does not ordinarily possess any apparent advantages over flame temperature measurements made by the line reversal method or by absorption-emission pyrometry (Cf. Sec. 3). The two-color technique may, in fact, be more difficult to apply in practice since it is usually necessary to obtain independent information regarding emissivities which may be as difficult to measure experimentally as the flame temperatures themselves. However, if the variation of emissivity with temperature can be calculated as, for example, in a rocket exhaust jet, then the two-color technique appears to possess a very real advantage and may lead to results which can be obtained only with considerable difficulty by other means.[25]

The presence of excited sources of intense radiation is less likely to cause erroneous results in flame temperature measurements by the two-color method than by the line-reversal technique, provided the radiant energy emitted from abnormally excited radiators constitutes only a small fraction of the total radiant energy emitted over the wavelength regions under study. However, only temperature measurements over a relatively large region of the flame zone are possible whereas the line-reversal technique permits at least limited control by judicious introduction of the added radiating and absorbing material (Cf. Sec. 3). In view of the fact that the two-color technique for measuring flame temperatures possesses both advantages and disadvantages compared to other methods, its choice for application to any given problem will evidently depend on the particular investigation which is to be carried out.

[30] Equation (3) suggests a very direct test for the existence of blackbody or greybody emitters in the gases formed during a combustion process. Thus, if the observed color temperatures are independent of the arbitrary wavelengths $\lambda_1$ and $\lambda_2$, then it is reasonable to conclude that the right-hand side of Eq. (3) vanishes and that therefore blackbody or greybody emitters are present. Kracek and Benedict have used this criterion, among others, to demonstrate the existence of blackbody emission in their closed chamber studies on propellant gases by replacing the wavelengths $\lambda_1$ and $\lambda_2$ by wavelength regions of finite widths (see Ref. 24).

### 3. Temperature Measurements by Use of the Reversal Technique

*A. Historical Introduction.*—The reversal techniques for the measurement of flame temperature are based on a straightforward application of the law which Kirchhoff formulated after his classic experiments designed to show the coincidence of the sodium lines with the Fraunhofer *D* lines.[31] Two types of application of the reversal technique may be distinguished. They are designated in the following discussion as absorption-emission pyrometry and the line-reversal method, respectively.

In absorption-emission pyrometry the flame temperature is determined by a comparison of the spectral brightness of the flame with the spectral brightness of an arbitrary source of radiation for all of the radiation emitted in a given wavelength region which may include an arbitrary number of absorption bands. This method was first used by Kurlbaum[32] in 1902 to determine the flame temperature of a candle. The name absorption-emission pyrometry was introduced by Jacobs and Scholnick[28] who have employed this method for temperature measurements of rocket flames and exhaust jets. Some of the errors inherent in flame temperature measurements by absorption-emission pyrometry were discussed by Lummer and Pringsheim[33] in 1902 and will be pointed out later in this section.

The line-reversal technique is similar to absorption-emission pyrometry except that the comparison of spectral brightness is restricted to individual wavelengths corresponding to electronic,[7, 34–39] vibrational,[36, 40, 41] or rotational[34] transitions. The method was introduced by Féry[7] in 1903 who used the resonance lines of sodium and lithium. Bauer[34] and Schmidt[36] appear to have made the first use of infra-red absorption bands. The line-reversal technique seems to have been employed more frequently for flame temperature determinations than any other optical method.

*B. Theory of Temperature Measurements by the Reversal Technique.*—The physical principles involved in temperature measurements by the line-reversal method and by absorption-emission pyrometry are the same. It is therefore convenient to present a unified description of the theory and to point out some of the sources of error which are more likely to arise in one case than in the other.

If statistical equilibrium exists between translational energy states and either electronic or vibrational or rotational energy states, then the flame temperature can be determined by a comparison of the spectral brightness of the flame with the spectral brightness of an arbitrary source for radiation produced by electronic transition (e.g., resonance lines of the alkali metals,[7, 34–37] green line of thallium[40]), vibrational transition (e.g., 2.7 $\mu$-band of $H_2O$, 4.4 $\mu$-band of $CO_2$[36, 40, 41]), or rotational transition (e.g., 25 $\mu$-band of $H_2O$[34]). If vibrational and electronic equilibrium do not obtain, it may still be possible to make a significant measurement by the use of rotational lines. If all three types of measurements give identical results, as has been shown to be the case for a Meker burner,[34, 36, 37] then it is reasonable to suppose that statistical equilibrium exists between translational energy states on the one hand and electronic, vibrational, and rotational energy states on the other hand. Reliable flame temperature measurements can be made by showing the simultaneous reversal for two or more emission lines as has been done, for example, for the red lines of lithium and the yellow lines of sodium.[7, 35] Flame temperature determinations by absorption-emission pyrometry are made by noting reversal over a relatively wide wavelength region.[28, 32] The desirability of showing the simultaneous reversal over two or more spectral regions was emphasized as early as 1902 by Lummer and Pringsheim.[33]

If statistical equilibrium between electronic and translational energy is not maintained, then

[31] G. Kirchhoff, *Monatsber. der Berl. Akad.*, October, 1859; *Pogg. Ann.* **109**, 148 (1860); *Abhandl. der Berl. Akad.*, 1861.
[32] F. Kurlbaum, *Physikalische Zeits.* **3**, 187 (1902); *ibid.* **3**, 332 (1902).
[33] O. Lummer and E. Pringsheim, *Physikalische Zeits.* **3**, 233 (1902).
[34] E. Bauer, *Comptes Rendus* **147**, 1397 (1908); *ibid.* **148**, 908 (1909); *Le Radium* **6**, 110 (1909).
[35] E. Griffiths and J. H. Awberry, *Proc. Roy. Soc.* (London) **A123**, 401 (1929).
[36] H. Schmidt, *Ann. der Physik* **29**, 971 (1909).
[37] H. Kohn, *Ann. der Physik* **44**, 749 (1914).
[38] F. Kurlbaum and G. Schulze, *Verh. der Deuts. Physikalischen Ges.* **8**, 239 (1906).
[39] E. Pringsheim, *Scientia* **13**, 188 (1913); *Jahresber. der Schles. Ges. für Vaterl. Kultur*, 1912.
[40] F. Henning and C. Tingwaldt, *Zeits. für Physik* **48**, 805 (1928).
[41] E. Buchwald, *Ann. der Physik* **33**, 928 (1910).

the measured electronic temperature may be either higher or lower than the local translational temperature. Abnormal electronic excitation has been observed, for example, for the emission bands caused by the C-H and C-C radicals.[34, 42]

Since a wide wavelength region is involved in temperature measurements by absorption-emission pyrometry, the error introduced by the presence of luminescence may not be as large as the error introduced into flame temperature measurements when a narrow emission line is chosen for comparison of spectral brightness. On the other hand, the requirements of absorption-emission pyrometry are far more stringent than those of the line reversal method in the sense that, ideally, statistical equilibrium must be reached for all of the emitters which radiate energy lying in a wide wavelength region. The line-reversal method requires only that statistical equilibrium exists with respect to a particular energy transition. Thus the advantages and disadvantages of the two methods can be summarized by the following two statements:

1. Absorption-emission pyrometry will usually not give an exact value of the flame temperature because complete statistical equilibrium for all of the emitters may not be reached. However, even in the presence of some luminescence the temperature measurement will usually not be greatly in error if a sufficiently wide wavelength band is used.
2. The line-reversal technique will give a correct value for the temperature if the emitters of radiation are excited thermally and are therefore in statistical equilibrium with the remaining gases. If statistical equilibrium does not exist, then the line-reversal method may lead to results which are greatly in error.

The reversal technique involves matching the spectral brightness of an arbitrary source against the spectral brightness of a given flame. At the point of reversal the spectral brightness of the source and flame are identical so that the source cannot be differentiated from the flame when it is viewed through the flame. Therefore,

$$\epsilon(\lambda, T_S)J(\lambda, T_S)=\epsilon(\lambda, T_F)J(\lambda, T_F) + \epsilon(\lambda, T_S)J(\lambda, T_S)[1-\alpha(\lambda, T_F)] \quad (6)$$

where $T_S$ denotes the temperature of the comparison source, $T_F$ the temperature of the flame, $\epsilon(\lambda, T)$ the spectral emissivity at the temperature $T$, and $\alpha(\lambda, T)$ the spectral absorptivity at the temperature $T$. Equation (6) is valid only if the flame zone is at a uniform temperature. Temperature measurements on nonisothermal combustion zones will be considered more fully in Sec. 5.

The spectral reflectivity of the flame is assumed to be negligibly small compared to the spectral absorptivity in Eq. (6). If this is not the case, as might be true for wavelengths for which no well-defined absorption bands exist, then the flame temperature measured by the reversal technique is lower than the true flame temperature.[33] The spectral reflectivity will not necessarily be negligibly small in absorption-emission pyrometry. It may therefore be necessary to make auxiliary measurements in order to determine the magnitude of the correction which should be introduced.[33] Henning and Tingwaldt[40] have shown that the reflection coefficient of the Bunsen flame over a wide wavelength region is negligibly small.

From Eq. (6) it follows that

$$\epsilon(\lambda, T_F)J(\lambda, T_F)/\epsilon(\lambda, T_S)J(\lambda, T_S)=\alpha(\lambda, T_F). \quad (7)$$

The relation between the flame temperature $T_F$ and the temperature $T_S$ can be determined by comparing Eq. (7) with Kirchhoff's law,

$$\epsilon(\lambda, T_F)J(\lambda, T_F)/J(\lambda, T_F)=\alpha(\lambda, T_F), \quad (8)$$

where $J(\lambda, T_F)$ is, as usual, the spectral brightness of a blackbody at the temperature $T_F$. Since the spectral brightness of a nonblackbody source at the temperature $T_S$ is, by definition, the same as the spectral brightness of a blackbody at the brightness temperature $T_{S_{\mathrm{br}}}$ it follows from Eq. (7) that

$$\epsilon(\lambda, T_F)J(\lambda, T_F)/J(\lambda, T_{S_{\mathrm{br}}})=\alpha(\lambda, T_F). \quad (9)$$

Comparing Eqs. (8) and (9) shows that

$$T_F=T_{S_{\mathrm{br}}} \quad (10)$$

at the point of reversal. If the arbitrary source is

[42] N. R. Tawde and J. M. Patel, *J. Univ. Bombay* **6**, 29 (1937).

a blackbody then $Ts_{br}$ is equal to the true temperature of the source and, therefore, the flame temperature and the true temperature of the source are identical at the point of reversal for this special case.

A description of the experimental procedure used in the reversal technique may be found in the literature.[43, 44] Specific applications to internal combustion engines[26, 45, 46] and stationary gas flames[40, 47–49] have been discussed by a number of authors. The line-reversal method appears to have been used extensively only in connection with the resonance lines of the alkali metals which are produced by electronic transitions. Since equilibrium with respect to the rotational energy states is reached very rapidly, it may prove desirable to revive some of the earlier applications[34] of the line-reversal technique for those cases where the presence of energy sources and sinks may vitiate results based on the assumption of the existence of statistical equilibrium with respect to electronic energy states. Some recently suggested experimental procedures for making the line-reversal technique self-recording by use of a movable wedge[25] or a Kerr cell[50] appear to be of interest.

In absorption-emission pyrometry as used by Jacobs and Scholnick[28] the brightness over an arbitrary wavelength region of a given source viewed through the flame is matched photoelectrically against the unattenuated brightness of the same source. At the point of balance Eq. (6) must be satisfied, from which the validity of Eq. (10) may be inferred. The experimental arrangement used by Jacobs and Scholnick[28] is suggested by the earlier work of Rosetti,[3] Wanner,[51] Kurlbaum,[32] and others.

When the line-reversal technique is used for radiation emitted by a constituent which is not normally present in the combustion zone, then temperature measurements can be made over a restricted region of the flame. This may be achieved by careful introduction of the added material.[36, 37, 40] Flame temperature measurements when not made at the well-defined emission lines of a substance which is normally absent from the flame give effective average values over the entire flame. Similar results are obtained for the reversal of resonance lines when totally colored flames are used.[43] The effective temperatures measured by the reversal technique over regions of the flame which are not at a uniform temperature are complicated functions of the flame geometry and temperature inhomogeneities, as has been shown by actual measurements as well as by approximate calculation for a simplified case.[35]

A discussion of the evidence for and against the establishment of statistical equilibrium with respect to a specific mode of excitation in any given case is outside of the scope of this survey. For considerations of the validity of flame temperature measurements by use of the $D$-line of sodium, reference should be made to the published literature,[45, 52–54] and particularly to recent articles by David,[55, 56] Young,[57] and Pugh[58] which suggest the formation of relatively stable molecules of abnormal energy content which in turn may cause the production of abnormally excited sodium atoms. A discussion of the effect of thickness of the flame zone on experimental results and of temperature measurements on nonisothermal regions is deferred to Sec. 5 of this report.

## 4. Modification of the Line-Reversal and Two-Color Techniques

The flame temperature of a given source can be determined through the application of an experimental procedure similar to that used in the reversal technique without, however, requiring that the condition of reversal be fulfilled. The relation between observed radiant intensities, the temperature and the emissivity

[43] B. Lewis and G. von Elbe, Ref. 9, p. 707.
[44] G. W. Jones, B. Lewis, J. B. Friauf, and G. St. J. Perrot, *J. Am. Chem. Soc.* **53**, 869 (1931).
[45] A. E. Hershey, *Ind. Eng. Chem.* **24**, 867 (1932); *Trans. Am. Soc. Mech. Eng.* **58**, 195 (1936).
[46] A. E. Hershey, *Chem. Rev.* **21**, 431 (1937).
[47] H. H. Kaveler and B. Lewis, *Chem. Rev.* **21**, 421 (1937).
[48] G. W. Jones, B. Lewis and H. Seaman, *J. Am. Chem. Soc.* **53**, 3992 (1931).
[49] H. H. Lurie and G. W. Sherman, *Ind. Eng. Chem.* **25**, 404 (1933).
[50] C. M. Wolfe, Aerojet Eng. Co. Report No. 327, 1948.
[51] H. Wanner, *Physikalische Zeits.* **3**, 112 (1901).
[52] W. T. David, *The Engineer* **157**, 558 (1934).
[53] B. Lewis and G. von Elbe, *Engineering* **139**, 168 (1935).
[54] R. Minkowski, H. G. Müller, and M. Weber-Schäfer, *Zeits. für Physik* **94**, 145 (1935).
[55] W. T. David, *Phil. Mag.* **23**, 251 (1937).
[56] W. T. David, *Nature* **159**, 407 (1947).
[57] G. H. Young, Chem. Res. and Dev. Dept., Ministry of Supply, Report No. 207/R/47.
[58] B. Pugh, R. A. E. Technical Note, GAS 19, 1946.

of the background source, and the temperature of the flame under study can always be determined by a straightforward application of Kirchhoff's law and of Planck's (or Wien's) equation. A recent illustration of this type of measurement has been discussed by Silverman.[59]

Silverman has described a modified reversal technique with reference to an experimental arrangement in which the spectral light intensity is measured through the length of a linear deflection recorded by a model 12C Perkin-Elmer infra-red spectrometer. From Planck's law the following two basic equations are obtained:

$$D_S = k\epsilon_S[\exp(c_2/\lambda T_S) - 1]^{-1} \qquad (11)$$

and

$$D_F = k\epsilon_F[\exp(c_2/\lambda T_F) - 1]^{-1}, \qquad (12)$$

where $D_S$ is the deflection produced by the light emitted from a globar whose temperature is $T_S$ and whose emissivity is $\epsilon_S$, $D_F$ the corresponding deflection produced by the radiant intensity emitted from the flame at the temperature $T_F$ if the emissivity of the flame is $\epsilon_F$, $k$ a constant at a given wavelength which varies as $\lambda^{-5}$ and depends on the amplification characteristics of the instrument used for study, and $c_2$ the second radiation constant. The deflection $D_t$ produced by the light emitted from the globar and transmitted through the flame is given[60] by the relation

$$D_t = D_S(1 - \epsilon_F) \qquad (13)$$

as an obvious consequence of Kirchhoff's law. From Eqs. (11), (12), and (13) it can readily be shown that

$$c_2/\lambda T_F = \ln\left\{1 + \frac{D_S - D_t}{\epsilon_S D_F}[\exp(c_2/\lambda T_S) - 1]\right\}. \qquad (14)$$

[59] S. Silverman, paper presented before the Symposium on Combustion and Flame and Explosion Phenomena, University of Wisconsin, September, 1948.

[60] Direct measurement of the quantity $D_t$ is made possible by introducing a rotating sector between the light source and the flame. Only the a.c. output of the receiver is then amplified and recorded.

Reference to Eq. (14) shows that the flame temperature is uniquely determined by the observed deflections without explicit knowledge of $\epsilon_F$. It is also evident that Silverman's procedure for determining flame temperature is subject to the same limitations as the reversal methods.

A method for measuring flame temperatures which is similar in experimental detail to that of Silverman although in principle it is actually an application of the two-color technique has been proposed by Wolfe.[61] One of Wolfe's procedures for measuring flame temperatures rests on the assumption that the radiant energy emitted from the $2.7\mu$- and $4.4\mu$-bands of water and carbon dioxide, respectively, is of thermal origin. The flame temperature can then be calculated from the observed intensity ratio in the two wavelength regions provided the emissivity ratio for the two selected wavelength regions is known, which is not generally the case. Alternately, the flame temperature can be determined directly from intensity measurements at one wavelength if the absolute value of the emissivity is known. The existence of thermal radiation from carbon dioxide in the Bunsen flame seems to be indicated through the work of Paschen[62] and Schmidt[36,63] done many years ago. However, there is some uncertainty concerning the existence of statistical equilibrium between carbon dioxide and the remaining flame gases in certain combustion flames.[64] In view of this fact, it seems difficult to predict whether or not the two-color emission technique or the absolute emission technique of Wolfe will lead to significant results for a given flame. Wolfe's method for measuring the radiant intensities at $2.7\mu$ and $4.4\mu$ by means of lead sulfide or lead selenide cells in combination with appropriate infra-red filters offers interesting practical possibilities.

[61] C. M. Wolfe, *Project Squid, Technical Memo. No. NYU-2*, April, 1948.

[62] F. Paschen, *Ann. der Physik* **50**, 409 (1893); *ibid.* **51**, 1 (1894).

[63] H. Schmidt, *Ann. der Physik* **42**, 415 (1913).

[64] K. J. Laidler, *J. Chem. Physics* **17**, 221 (1949).

# A Sophomore Laboratory Experiment on Determining $\gamma$ for Air

IRVING L. KOFSKY
*Syracuse University, Syracuse, New York*

ALMOST 100 years ago, Assmann[1] devised a method of determining $\gamma$, the ratio of the specific heat of a gas at constant pressure to its specific heat at constant volume. The experiment is referred to by Cork.[2] We have found that it gives excellent results in our second-year laboratory on mechanics and heat. Pedagogically it covers important concepts in both these subjects. It is somewhat similar to Rüchardt's method,[3] but the apparatus is much simpler to construct.

In effect, Assmann's method compares the periods of a mercury column in a U-tube, first oscillating freely, and then working against a force increased by adiabatic compressions of the air in one arm. Consider a U-shaped column of mercury of length $L$ and density $\rho$, vibrating in a tube of uniform bore. For the moment, consider both stoppers (Fig. 1) to be removed. The restoring force on the column is seen to be $2\rho gAx$, where $x$ is the displacement from the equilibrium position, $A$ the cross-section area of the tube, and $g$ the gravitational acceleration. Therefore, by the rules of simple harmonic motion, the period of oscillation is, neglecting frictional effects,

$$T_1 = 2\pi(L/2g)^{\frac{1}{2}} \tag{1}$$

because the mass being accelerated is $LA\rho$.

Now, if *one* arm of the tube is corked, the restoring force in that arm is increased by $A\Delta P$, where $\Delta P$ is the small change in pressure on the surface of the mercury at displacement $x$. Since the volume $V$ of air in the closed tube will undergo rapid and, therefore, approximately adiabatic compressions and decompressions, $PV^{\gamma}$ is constant. Then

$$\Delta P = -\gamma P(\Delta V/V)$$

or

$$-\gamma(\rho Hg)(xA/hA) = -\gamma\rho(H/h)gx, \tag{2}$$

where $h$ is the height of air in the closed tube above the mercury, and $H$ the atmospheric pressure (and therefore the equilibrium pressure on the air in the corked arm) expressed in cm of mercury. A new force constant of $2\rho gAx + \gamma\rho g(H/h)Ax$ gives for the period of the oscilla-

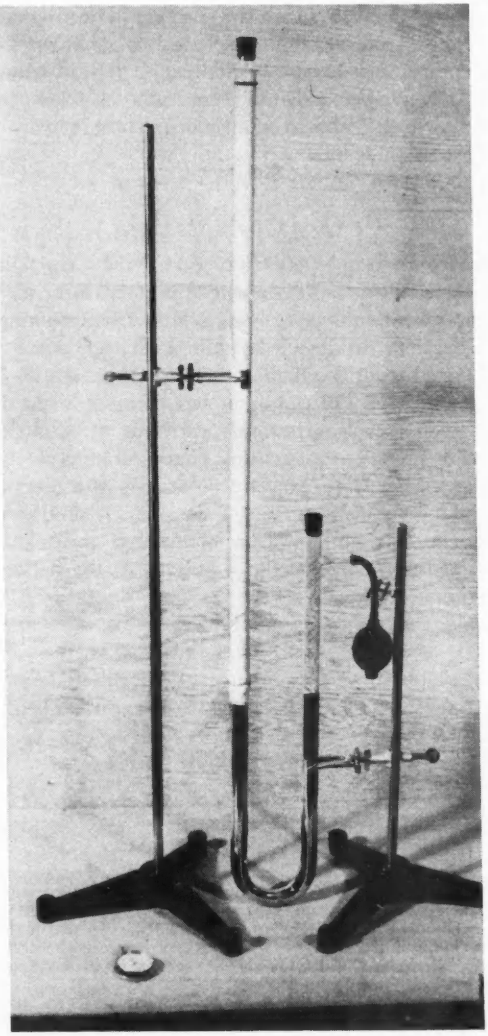

FIG. 1. Mercury column and U-tube for an experiment to determine $\gamma$ for air. In laboratory practice, the apparatus stands in a shallow pan to catch the mercury in case the U-tube is broken. To diminish the flow of heat to and from the air contained in the tube, asbestos tape is wrapped around the longer arm and secured with rubber bands.

[1] Assmann, *Pogg. Ann.* **85**, 1 (1852).
[2] Cork, *Heat* (Wiley, ed. 2, 1942), p. 68.
[3] *Ibid.*, p. 67; Rüchardt, *Physikalische Zeits.* **30**, 58 (1929).

tions of the mercury,

$$T_2 = 2\pi\left\{\frac{L}{2g+\gamma\dfrac{Hg}{h}}\right\}^{\frac{1}{2}}, \tag{3}$$

where friction is again neglected.

Squaring both Eq. (1) and Eq. (3), and dividing, we get

$$\gamma = \frac{2h}{H}\left(\frac{T_1^2}{T_2^2} - 1\right). \tag{4}$$

Therefore, the only measurements the student need make in the laboratory are the heights of the corked air column and of the mercury column in a barometer, and the two periods of the oscillating mercury. The canceling out of parameters clearly shows the student the advantage of fully understanding the theory behind an experiment before doing it. Students are prone to measure $L$ and $A$ immediately upon entering the laboratory, and one poorly prepared group was observed attempting to measure the initial displacement of the mercury column.

The mercury in our apparatus is given its initial displacement by placing a rubber stopper in the shorter arm and building up air pressure there by means of an aspirator bulb fitted with a pinch clamp. In this way the vertical position of the U-tube need not be disturbed in starting the oscillations. Slightly better results are obtained by insulating the air column with asbestos tape, so that the compressions and decompressions are more nearly completely adiabatic.

Typical data are: $h=84.0$ cm, $H=75.4$ cm of mercury, $T_1=10.8$ sec, and $T_2=8.5$ sec. These give $\gamma=1.38$. Our tubes are of 19-mm Pyrex, and mercury columns about 75 cm long are used. With these dimensions it is possible to get, with initial displacements of roughly 8 cm, about 15 "uncorked" and 12 "corked" oscillations, before the amplitude dies out due to friction between the mercury and the wall. It is found that tubes of smaller bore exhibit serious frictional effects, probably because the ratio of weight of mercury to area in contact with the wall decreases linearly with decreasing radius of the tube. Our neglect of friction in the derivation of Eq. (4) is somewhat justified by the fortunate circumstance that we divide Eq. (1) by Eq. (3). Physically, we have in each case damped simple harmonic motion with its corresponding decrease in the natural frequency of the mercury column; this changes the expressions for $T_1$ and for $T_2$ by a small fractional amount, and on division the error is to a large extent canceled.

The experiment has been tried with water instead of mercury in the U-tube; but viscous lamellar motion of the water, short periods, and large attenuation of the amplitude make this a poor, if not worthless, experiment.

One disadvantage worth mentioning is the critical dependence of $\gamma$ on the ratio of the squares of the periods; therefore, these periods must be measured very carefully with a stopwatch. In our laboratory, the student compares his values of $\gamma$ obtained from this experiment and from the Clément and Désormes experiment.

## Eddington Prize

The Institut International des Sciences Théoriques, Palais des Academies, Brussels, offers the Eddington Prize amounting to 50,000 Belgian francs for a memoir on the general subject, Exposition and Criticism of the Concepts of Eddington concerning the Philosophy of Physical Science. The members of the award committee are I. Dockx, Director of the Institute, L. de Broglie, Secretary of the Academy of Science of Paris, Th. de Donder, Professor of the University of Brussels, F. Gonseth, Professor at the Polytechnic School, Zurich, and E. A. Milne, Professor at Oxford University.

Five copies of each competing memoir must reach the secretary of the Institut International des Sciences Théoriques, 221 Avenue de Tervueren, Brussels, before December 31, 1950. Every participant is requested to sign his paper by a symbol or motto and to put in an accompanying sealed envelope his name and address, together with a copy of the symbol or motto.

# Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

## 45. *Vanity Fair* Caricature of LOUIS PASTEUR

E. C. WATSON
*California Institute of Technology, Pasadena 4, California*

THE *Vanity Fair* caricature of LOUIS PASTEUR (1822–1895) has been often reproduced, but to the best of my knowledge the written account that accompanied it has not. While this account is not as interesting, or as penetrating, as many that appeared in the *Vanity Fair* series, it is nevertheless worth reproducing. It appeared on January 8, 1887.

### M. Louis Pasteur

"LOUIS PASTEUR was born four-and-sixty years ago at Dôle, the son of a tanner who had been a soldier, went to school at Besançon, and soon displayed a bent for chemistry and plunged into juvenile experiments. He became learned in tartrates and paratartrates, he investigated molecular dissymmetry, fermentation, and putrefaction, and finally gave himself up to microscopic organisms, which led him up to the further development of inoculation as a protective and curative agent in disease. He became famous throughout Europe as one of the first chemists of the age, and was already known to every man of science in the world, when he became also known to men in general as the inventor of the vaccinal treatment of the dreaded malady Hydrophobia. No sooner was this known than the great chemist was invaded by men of every condition and every country, and some thousands of patients, the victims of bites from dogs either mad or supposed to be mad, have now passed before the operating-table of the Rue d'Ulm. It cannot be said that the treatment has proved itself successful, for many of those subjected to it have subsequently died. This, however, though it may diminish M. Pasteur's reputation as a destroyer of hydrophobia, does not detract from his ability as a chemist, and there is no doubt that he is a very great man indeed. He has worked incredibly hard, and once brought on himself, by work, an attack of paralysis. He is a vivisector, yet fond of animals, and a very humane and kindly man, who, though he is greatly denounced by his opponents, is beloved by all his friends."

"Hydrophobia." [From *Vanity Fair*, January 8, 1887.]

With this number we must end for the time being the reproduction of *Vanity Fair* caricatures of interest to physicists. Others that should be added later when the copyright laws permit are of even greater interest than those already used. These include Lord Rayleigh, the Curies, William Crookes, Oliver Lodge, Marconi, William Ramsay, Hiram Maxim, Lord Kelvin and others.

# Benefits of Industrial Experience to the Physics Teacher

J. L. Glathart
*Albion College, Albion, Michigan*

In past years the profession of physics was largely an academic one. The student who prepared himself to be a physicist expected, in the great majority of cases, to earn his livelihood by teaching the subject. A few physics graduates entered the Bureau of Standards or other government agencies and a few found positions in industry. But in this or any other country, most of the physicists were to be found in the educational institutions. There was little demand elsewhere for their talents. In those days a physicist was, typically, one who taught physics.

More recently, particularly during and after World War II, the situation has changed. True, the young Ph.D. in physics may still, if he desires, look forward to a teaching career; his opportunities in that field have never been better. But now both industry and government are actively and aggressively bidding for his services. Or he may even plan toward a future as an independent consulting physicist—something almost unheard of in former times.

These same possibilities are also available, of course, to the older physicist who may already have spent some years in the teaching field. He may, if he wishes, enter an industrial laboratory, or a government laboratory, or the consulting field. The profession of physics has expanded to the point where it now involves a large element of choice.

Since other opportunities are available, no physicist is compelled to remain in the teaching field. If he stays on the campus, it is because he chooses to do so. And there are many who will always find their greatest satisfactions in teaching.

However, much can and has been said concerning the advantages to be derived by the teaching physicist from a sortie—however brief—into one of these other fields open to him. Every academic physicist would probably grant in principle the value of a teacher's having some experience in those fields where physics is applied rather than merely expounded. But when he considers personally making such a venture, involving radical changes in his accustomed habits and routines, the physics teacher may quite justifiably hesitate and raise questions. Perhaps a few of these questions can be answered—at least in part—by those of us who have taken the excursion and found the trip both pleasant and beneficial.

If he enters an industrial or government laboratory, will he be burning all his academic bridges behind him?—The answer to that is unequivocally *no*. If a professor of physics decides, for example, to become an industrial physicist for a while, or to do research in a government laboratory, there is no reason why he cannot later reverse the process and return to teaching. Indeed, college administrators usually look with particular favor on the man whose background includes some so-called "practical" experience as well as previous teaching.

How complete a revolution in his mental processes and habits and attitudes will be involved? Of course this will vary widely with different individuals. Since an article[1] in a recent issue of this journal analyzed in considerable detail the conditions encountered by the physicist working in a government laboratory, our comments will be confined to the situations which are likely to be met by the teaching physicist who goes into industrial research.

It should be said, parenthetically, that the necessary readjustments may be minor if our academic physicist has been a university professor who already has spent much of his time in research, teaching perhaps only one or two highly specialized graduate courses. But what about the ordinary physics teacher who is used to spending most of his time in the classroom, handling the usual undergraduate or preparatory courses, and trying to do a bit of research on the side? What readjustments is he likely to find necessary if he goes into industry? What new attitudes and approaches will he learn? Just why and how is the experience so "broadening"?

First of all, an experience in industrial research

[1] Walker, "The scientist and government research," *Am. J. Physics*, **17**, 30–34 (1949).

involves a great shift in the viewpoint from which the teacher is wont to regard his subject. The teacher is primarily concerned with fundamental principles. To him, they are the all-important aspect of his subject—the one which he continually emphasizes. Newton's laws, the conservation laws, Ampere's and Faraday's laws, and others—these occupy key positions in his thinking, and, in spite of himself, he is inclined to acquire for them a kind of exaggerated respect, almost a reverence. Whether or not he realizes it, they tend to be regarded by him as the "eternal truths and immutable laws of Nature," instead of merely tentative and often only approximate relationships among certain variable quantities. An extreme illustration of this viewpoint was the confusion and alarm among some older physicists at the time of the advent of Einstein's relativity theory, a mental distress which is said to have led in a few cases to insanity and suicide.

For anyone inclined toward this reverential view of natural laws, a spell in industry is most salutary. For in industry the emphasis is not so much on the means of solving a problem as on the solution itself. All things which contribute to a practical solution, or even to an acceptable compromise, are equally valid, whether they be fundamental principles, empirical relations, or rules of thumb. It is the result which counts, and time is of the essence. The criterion by which the result is judged is not its approach to ultimate reality or to absolute truth, but merely what it may contribute to the development and saleability of a product. This attitude towards even scientific problems is not to be condemned, of course; industry could not do otherwise and still fulfill its primary purpose, which is to improve and sell its products. But to the academic physicist, who is accustomed to emphasize fundamentals and who cherishes physics for its own sake, this attitude may come as a distinct shock. In spite of himself, he may feel some resentment that the science which he loves so deeply is regarded by his associates in industry as merely a tool to be used for the solution of mundane problems, and used often in a more or less cavalier manner, without appreciation of its deeper philosophical meanings and implications. The academic physicist in industry may occasionally feel somewhat like a master carpenter who sees his favorite wood chisel, to the sharpening and polishing of which he has devoted such loving care, being used to pry a nail out of a board.

So our physicist must be prepared for certain readjustments in his mental attitude toward his subject. He must banish that lingering feeling, of which, indeed, he may be unaware, which was expressed by the mathematician when he said: "Here is a beautiful new theorem. Thank God, no one will ever find a use for it!" But if this readjustment in attitude can be accomplished, then the chances are that our physicist will find a new interest and a new delight in the many opportunities offered by industry for the illustration and application of fundamental physical principles. Once he reconciles himself to industry's essentially different goal, he will find that there is much of value in its method and procedure.

An experience in industry will probably bring still further benefits to the teacher-turned-industrial-physicist. Most of the subject-matter problems with which he deals as a teacher are ready-made, each specifically designed to illustrate one or more physical principles. And the examples of the application of such principles in industry and engineering, to which the teacher may refer, are also carefully selected and simplified in order that the students may not be confused. All this, of course, is necessary and desirable in the teaching process, but it exposes the teacher himself to certain dangers. First, his ability to formulate or solve such over-simplified problems may lead to a certain degree of complacency. An even more serious danger is that too great a preoccupation with selected and simplified data will dull the teacher's appreciation of the actual complexity of nature as a whole. For, in the academic laboratory, nature is broken down, so to speak, into little pieces, and of these only the simpler ones are chosen for study. We "begin" and we "finish" a course in heat, or electricity, or mechanics. In the latter, for example, we study only a little of the whole complex theory of elasticity, and we ignore completely the very important problem of what happens beyond the elastic limit. Why does a steel beam collapse? Why does a glass bottle break? Why does a rubber tire blow out? What is the physical basis

of such failures? Can anything be done about this? The physics textbook usually manages to avoid such questions. The physics teacher may, indeed, be only vaguely aware of their importance.

But when the physicist enters the industrial field, it is that kind of basic question which confronts him immediately. No one simplifies it for him or selects the data so that the answer will come out in small whole numbers. The search for an answer may, and probably will, involve every scientific field with which he may be familiar, and others in which his knowledge is meager. Nature in the raw is infinitely complex. A full appreciation of this fact is not always grasped in school, even by the teacher. But it comes quickly to the physicist who chooses to work on a typical industrial problem. Nothing will so quickly deflate his ego. The realization of one's own ignorance is truly an uncomfortable feeling, but it is said to be the beginning of wisdom.

The physics teacher should be prepared for certain restrictions on freedom of research and publication when he enters the industrial field. Industrial laboratories, particularly some of the larger ones, support a certain amount of fundamental research which may be largely unrestricted. But the newcomer to industry is likely to be impressed by the fact that in general his work is judged not so much by its contribution to the sum total of human knowledge as by its possible application to improve a product or reduce its cost. This leads necessarily to a certain curtailment in that freedom of research which the physicist enjoyed on the campus. He finds that he cannot so easily swing out of the main stream to explore some inviting tributary. Whether or not this restriction becomes onerous depends among other things on the temperament of the individual himself. Even should he feel somewhat inhibited, there is always the consolation that the main stream will probably not be lacking in points of interest peculiar to itself. Furthermore, the completion of a project which turns out to be of economic value yields a kind of satisfaction all its own.

The results of industrial research are likely to be published in trade journals rather than in those research publications with which the physics teacher may be more intimately acquainted. Although procedures vary with different companies, in general there is less freedom of publication in the industrial field than in the academic. This is understandable, of course, in view of the competitive factor in industry; and, on the whole, the situation is not as restricted as one might expect. Most companies are glad to approve for publication any research results which are of a general nature and which do not reveal trade secrets regarding any specific product or process. Accordingly, papers intended for publication in a scientific journal or trade magazine are subject to review by an appropriate administrative officer, who may request the alteration or deletion of certain passages, in the company's interest. Since it is the company which pays the salary of the researcher and the expenses of the research, one can scarcely challenge its rights to the economic benefits to be derived therefrom.

What kind of work will the physicist do if he goes into industry? Here it is hard to generalize because of the great variety in types of problems encountered in different industries. One thing can be depended upon: there will be no lack of variety. In academic work, the physicist may have racked his brain to think of suitable problems for investigation; in industry, problems come trooping in on one another's heels. While conducting an investigation into the mechanical strength of glass, for example, he finds himself engaged in other problems, possibly an analysis of the various methods of measuring density, or perhaps the determination of the service-life of glass tumblers in restaurant use. Further problems pop up in rapid succession: Why and how does the composition of certain glass bottles influence the effect which sunlight has on the beverages contained therein? How fast does a crack travel in brittle material, and what factors determine its speed? Does a glass window-pane slowly sag toward the bottom with the passing of centuries? If so, why? If not, why not?

Then, too, the industrial physicist may be called upon to solve problems having no direct relation to his own main research. Nominally he may be engaged in a project of more or less fundamental character, on x-ray crystallography or electron diffraction, let us say. At the same time he is on call as consultant to help with other

more immediate problems which arise in the normal operation of the plant. Such trouble-shooting may take him out of the plant, perhaps into the next state, or across the continent. These demands may be annoying at times, because they interrupt the continuity of his main investigation; but they are a constant challenge to his knowledge and ability, and they add variety and interest to his job.

What about the personal contacts in an industrial research position, compared with those of the academic world? Perhaps it will come as a surprise to the physicist who has spent many years in the educational field to find that the campus has no monopoly of the scholars of the land. There are men now engaged in the hurry and worry of modern industry whose wisdom and scholarship would grace any university lecture hall. Thus the physicist who transfers to industry need have no concern as to whether he will find congenial associates. If he has found many friends in the academic world, he will find many in the world of business. And these new contacts will be the more stimulating because of their wide variety. For in the academic field the people one associates with constitute a relatively homogeneous group; there are subject-matter differences, of course, but the various professors usually have comparable attitudes and backgrounds, and —if they avoid technicalities—they can readily understand and appreciate one another. In industry, on the other hand, this homogeneity is lacking. The research physicist will have to deal with all types of individuals, from his associates in the laboratory to the company executive (who may be a self-made man and proud of it) to the laborer in the plant who cannot understand why a man called "Doctor" does not dispense pills and potions. And his relations with these men, particularly with those in the plant, will differ from the personal relations to which he is accustomed in the academic field. In the classroom, the professor is the boss. He is accustomed to giving directions and expects, as a matter of course, that they will be observed. Out in the plant, the physicist may be in quite a different position. Far from being the boss, the research man is too often regarded as merely a nuisance. The test he wants to run or the experiment he wants to conduct may upset long-established plant routine or delay plant output during the test. Hence, there may be some opposition from superintendents or foremen interested in production schedules. The experimenter must be able to handle competently a wide variety of people, to gain the respect and secure the cooperation of even the so-called "practical" men. But if the Ph.D. will show a sincere appreciation of their know-how, which is often vital to the industry and could never be learned in school, they in turn will begin to respect his superior theoretical knowledge. And this respect will become sincere admiration if he can demonstrate that his theoretical knowledge can be used to improve the company's products or to solve the practical everyday problems encountered in the operation of the plant.

A college administrator recently remarked to a faculty group that both business and education would benefit if every teacher could spend a few years of his life in business, and every business executive could spend a few years in education. For teachers of some subjects, it might be difficult to secure such desirable breadth of experience; for the physicist, it is usually easy. Industry needs and welcomes his services, and the academic world will welcome him back afterwards.

Of course, the physicist may find his industrial research experience so enjoyable that he will have no desire to return to the classroom; he may indeed wonder why he did not make the shift years before. But the dyed-in-the-wool teacher will eventually return to his teaching, and he will be a more competent physicist and a more effective teacher when he returns. He will have profited most widely if his industrial research experience has extended over a period of years; but he will also gain much from short periods in the industrial field—periods made possible by summer vacations, sabbatical years, and semester leaves of absence.

It is true that, in a short period, the contribution which the average physicist can make to industry may be small. But, even so, when he returns to teaching, it will be with an enlarged mental horizon and a sounder appreciation of the ramifications of physics in areas of which he may previously have been unaware. Both he and his students will profit from his new attitudes, his

wider contacts, and his greater understanding of the practical applications of physics in the world outside the classroom.

If education is to meet the needs of today's world, it is imperative that the educator know that world as completely as he can. Particularly should he understand the ways in which his own subject is significant and useful in the complex pattern of our whole economic system. So, be our physics teacher young or graying, be his stay in industry a five-year stretch or a brief sampling during the summer, he will almost certainly be a better educator when he returns again to his teaching.

## A Simple Television Demonstration

ROBERT E. BENN
*Franklin Institute Laboratories for Research and Development, Philadelphia, Pennsylvania*

A LECTURE demonstration or laboratory experiment, utilizing two cathode-ray oscilloscopes and a photomultiplier tube, provides a graphic illustration of the mode of operation of a complete television system.

A schematic diagram of the system appears in Fig. 1. Light from a raster[1] formed by a moving spot on the screen of the first oscilloscope is focused on an object. Some of this light is reflected from the object to a photomultiplier tube connected to the second oscilloscope where an intensity-modulated pattern is produced. A reduced image of the raster (Fig. 2) appears on the object which is to be scanned. This image, while appearing to be an area of uniform illumination, is actually formed by a spot of light which traverses the image area in the same manner as in the original raster. When this spot of light falls on a region of the object having a high reflectivity, a relatively large amount of light is reflected. A portion of this light falls on the photomultiplier and a strong signal is produced. When the spot falls on a region of low reflectivity, less light is reflected and a weaker signal is produced. Thus, the signal amplitude is proportional to the reflectivity of corresponding points on the object. This signal is applied to the control grid of a cathode ray tube through the $Z$-axis amplifier, so that the intensity of the electron beam in the viewing oscilloscope is controlled point by point in accordance with the reflectivity of the scanned object. Light shields may be provided to prevent extraneous light from falling on the phototube.

[1] Raster—a television term, defined as a predetermined pattern of scanning lines which provides substantially uniform coverage of an area.

Similar rasters are displayed on the screens of the two oscilloscopes. Each raster resembles that shown in Fig. 2, where the arrows indicate the direction of movement of the spot of light. A high frequency sawtooth voltage applied to one pair of deflection plates in each cathode ray tube causes the beam to move across the screen at a constant velocity, as shown by the solid lines, and return with a high velocity, as shown by the dashed lines. Simultaneously, a low frequency sawtooth voltage applied to the other deflection plates causes the spot to move in a perpendicular direction at constant velocity. The displacement due to this latter movement separates the lines and thereby forms the raster. At the end of its travel the spot returns with high velocity to the starting point and begins tracing out the next cycle. By varying the frequency ratio of the two sweep voltages, the number of lines per frame can be varied.

A diagram of connections appears in Fig. 3. The rasters are generated by operating the internal sweep generator of the viewing oscilloscope at the line frequency and the internal sweep generator of the scanning oscilloscope at the

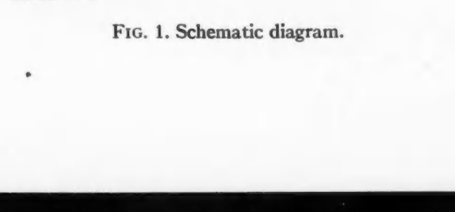


FIG. 1. Schematic diagram.

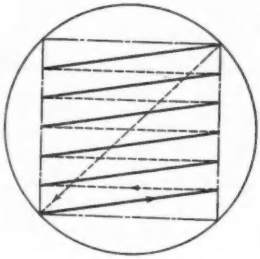

FIG. 2. Scanning and viewing raster.

frame frequency. Since the sweep voltage of each is applied to the $Y$-axis amplifier of the other, similar rasters appear on the two oscilloscopes. It should be noted that this method causes the scanning raster to be rotated 90° relative to the viewing raster. If the viewed image is to appear in its normal position, the scanned object should be rotated through a right angle.

Although almost any cathode ray oscilloscope can be used, with slight modifications, the Dumont Type 247 is ideal because the internally generated sweep-voltage is available externally at a terminal, and because it contains a suitable $Z$-axis amplifier. The photomultiplier used is a 931-A, and the cathode ray tubes are Type 5CP11-A. The phosphor color on the viewing tube is immaterial but that of the scanning tube should be P11 since its peak emission falls near the peak sensitivity of the 931-A. The multiplier voltage, $112\frac{1}{2}$ volts per stage, is secured from a bank of small 45-v dry batteries with $22\frac{1}{2}$-v taps.

The bandwidth of the system is limited primarily by the decay time of the light from the scanning tube phosphor. Since this decay is not instantaneous, the scanning spot tails out and limits the obtainable resolution. The multiplier load resistor, $R_L$, can be as high as 50,000 ohms without materially reducing the resolution.

The frame frequency should be high enough to eliminate flicker, about 30 cycle sec$^{-1}$. The line frequency can be varied to control the number of lines in the picture, but the limit imposed by considerations of resolution is about 3000 cycle sec$^{-1}$. (100 lines).

Using an $f$ 3.5 lens of 50-mm focal length with the scanner, this system can transmit printed matter, line drawings, and simple pictures with considerable clarity. The scanned area must be kept small, between $\frac{1}{2}$ inch and 1 inch on a side, in order that the amount of detail in the picture

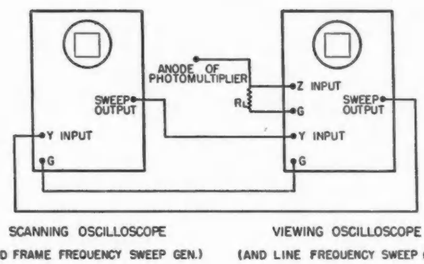


FIG. 3. Diagram of connections.

shall be within the capabilities of the system, and the intensity of the reflected light high enough to provide a sufficiently strong video signal. This equipment presumably could be used to reproduce photographic negatives by equipping the multiplier with a lens and placing the negative between multiplier and scanner. Various experiments on resolution and band width that can easily be performed demand only minor additions to the equipment.

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*. . . but if the physicist had not himself lost the high literary potential of Swift and Voltaire, he would exaggerate to much better purpose, and would handle the unfortunate creature called Man in a temper such as any one may renew who cares to go back to Bunyan or Dante or the Bible, not to mention the Prophets in particular:*

—HENRY ADAMS, *The Degradation of the Democratic Dogma.*

# Note on Pendulums

E. KATZ
*University of Michigan, Ann Arbor, Michigan*

IN a recent paper, "Demonstration experiments with pendulums," W. W. Sleator[1] pointed out that the time of oscillation of a rod about its end is not altered if other similar rods are attached to it at their centers of mass so as to lie in the plane of oscillation. Moreover, Sleator proved for a nonhomogeneous circular hoop oscillating in its own plane about an axis $S$ through a point of the hoop, that the center of oscillation also lies on the hoop, namely at the point $O$ where the hoop intersects the line through $S$ and its center of mass $G$.

The present note supplements Sleator's paper in showing that quite general statements of a similar but more complex kind can be visualized very simply by making use of a slight extension of Huygens' theory of the radius of gyration as described by Mach.[2] The concept of the radius of gyration is introduced in many books on mechanics but very little further use is made of it. The present note shows how useful this concept may be.

We start with two familiar definitions:

1. If $I$ is the moment of inertia about a specified axis and $M$ the total mass of an arbitrary pendulum, then
$$I = Mk^2 \tag{1}$$
defines the radius of gyration $k$ about that axis.
2. The center of oscillation of an arbitrary pendulum is the point $O$ on the line from the point of suspension $S$ through the center of mass $G$ where all the mass of the pendulum may be concentrated without altering the period of oscillation.

In Fig. 1 the length $l = SO$ is the length of the equivalent simple pendulum. Most textbooks show that
$$l = I_S/Mh, \tag{2}$$
where $h = SG$. According to Huygens-Mach it is extremely simple to prove for arbitrary pendulums the following equation (Proposition I):
$$SG \times GO = k_0^2 \tag{3}$$
where $S$, $G$, $O$ have the meanings stated above and shown in Fig. 1, and $k_0$ is the radius of gyration of the object about an axis through $G$

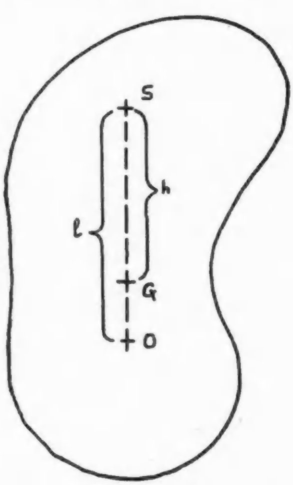


FIG. 1. A general pendulum, oscillating in the plane of drawing, suspended at $S$ with center of mass $G$ and center of oscillation $O$.

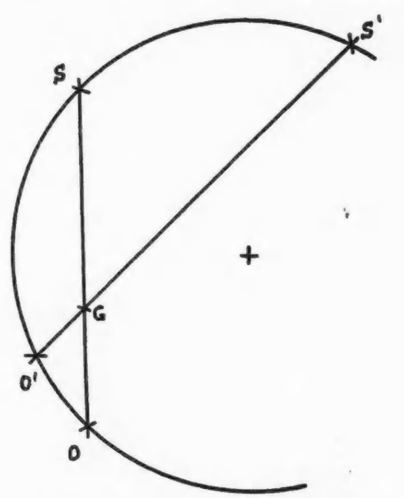


FIG. 2. If $S$ and $O$ are conjugate, then $S'$ and $O'$ are also conjugate.

[1] W. W. Sleator, *Am. J. Physics* **16**, 93 (1948).
[2] E. Mach, *The science of mechanics* (The Open Court Publ. Co., Chicago, 1919).

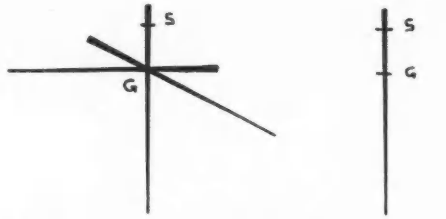


FIG. 3. A star made of equal nonhomogeneous rods fastened together at centers of mass $G$ and suspended from $S$ has same period of oscillation as a single rod suspended from the same point $S$.

parallel to that through $S$. This relation sets in evidence at once the well-known interchangeability of $S$ and $O$ and can be used for a very simple and elegant construction of $l$ or $k_0$ if the other elements (for instance $h$ and $k_0$, or $h$ and $l$) are given, as indicated by Mach.

In what follows we shall call *conjugate points* any pair of points $(S, O)$ which constitute a possible point of suspension and a corresponding center of oscillation. Formula (3) expresses the necessary and sufficient condition that two points on a line in the plane of oscillation and through $G$ be conjugate. Different pairs of conjugate points will, in general, correspond to different periods of oscillation, unless they lie on circles with $G$ as a center.

Now consider an arbitrary body of which one pair of conjugate points $S$, $O$ shown in Fig. 2 and the location of the center of mass $G$ (on $SO$) are given. The following new extension of Huygens' proposition can easily be proved (Proposition II): "The two points of intersection of *any* circle through $S$ and $O$ with *any* line through $G$ (both in the plane of oscillation) are conjugate points." Using Eq. (3) this statement boils down to a well known property of circles.

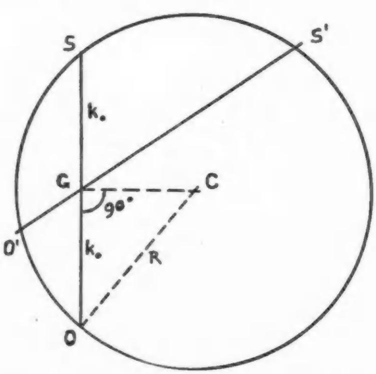


FIG. 4. If $S$ and $O$ are conjugate points on a nonhomogeneous circular hoop, the whole hoop is self-conjugate.

With the aid of Huygens' Proposition I the following statement (Proposition III) is simply proved: "Consider a number of nonuniform rods, all alike, fastened together at their centers of mass so that they all lie in one plane. This compound pendulum suspended from a point $S$ on one of the rods will have the same period of oscillation (swinging in its own plane) as when that one rod is suspended from $S$." Figure 3 shows such a system of rods.

The reason is, of course, that the distances $SG$ and $k_0$ are the same in both cases, hence $l$ and the period are the same also. The experiments described by Sleator are special cases of Proposition III, the rods being uniform and $S$ being at the end of one rod.

With the aid of Proposition II, the extension of Huygens' proposition, the following statements are easily proved (Proposition IV, Sleator's theorem): "Consider an inhomogeneous circular hoop oscillating in its plane about an axis passing through a point $S'$ on the hoop. Then the conjugate point $O'$ also lies on the hoop, namely at the other intersection with $S'G$."

To prove this all we have to show is, that the

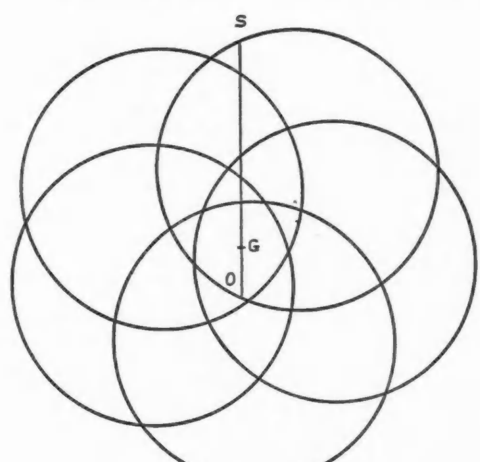


FIG. 5. A rosette of equal nonhomogeneous hoops fastened together at centers of mass $G$ and suspended from $S$ has the same period of oscillation as a single hoop suspended from the same point $S$.

hoop contains one pair of conjugate points, for according to Proposition II the whole hoop will then be self-conjugate. The conjugate relationship is most easily proved for the special pair of points $S, O$ on a line perpendicular to the radius through $G$ ($CG$ in Fig. 4). The radius of gyration about $C$ is $R$ since all mass elements lie at a distance $R$ from $C$, the center of the hoop. About $G$ we have:

$$k_0^2 = R^2 - (CG)^2$$

or

$$SG = GO = k_0.$$

Consequently $SG \times GO = k_0^2$ satisfying the condition (3) for $S, O$.

From the present standpoint it is clear that a whole plane rosette of equal, nonhomogeneous circular hoops, fastened together at their centers of mass and suspended from any point $S$ on any one of the hoops (see Fig. 5) will have the same period of oscillation as when that hoop alone is suspended from $S$. Consequently the whole rosette is self-conjugate.

One may inquire what types of (nonhomogeneous) wire figures are self-conjugate. The previous examples show that stars, circles and rosettes can be self-conjugate. The following construction shows that very general self-conjugate figures are possible. We start by drawing a circle of radius $k_0$ about a point $G$ (see Fig. 6). We shall arrange it so that $G$ becomes the center of mass and $k_0$ the radius of gyration about $G$ of our wire figure to be constructed. Next we draw a completely arbitrary curve in the plane of the circle, starting from a point $S$ on the circle and ending at the opposite point $S'$. For every point $P$ on the curve we locate a conjugate point $P'$ such that $PG \times P'G = k_0^2$. All points $PP'$ form together a closed curve. If now we load any pair of these conjugate points $PP'$ with masses that are inversely proportional to their distances from $G$ this insures that $G$ will remain the center of mass. At the same time the radius of gyration of the pair $PP'$ is $k_0$. These conditions still leave great latitude concerning the loading. If we load all points $PP'$ pairwise in this manner, that is, with masses that are inversely proportional to their distances from $G$ (the proportionality factor may vary from pair to pair) the whole curve thus loaded will still have $G$ for its center of mass. Since all pairs have the same radius of gyration $k_0$ about $G$ the whole curve will also have $k_0$ for its radius of gyration about $G$, hence will be self-conjugate. It is clear from this very general example that self-conjugation can be achieved with very complex figures of which stars and circles are certainly the simplest representatives.

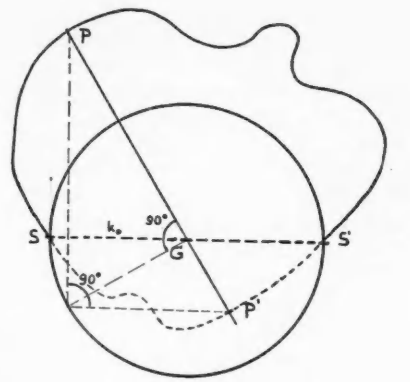


FIG. 6. Construction of a self-conjugate nonhomogeneous wire of general form.

In conclusion, it is a pleasure to thank Dr. Sleator for stimulating discussion.

*With great conscientiousness Maxwell repeated Cavendish's experiments. Something of the background of electrical science as Cavendish knew it will be recovered if we remember that in his day there was no known effect of an electric current by which measurements could be made. Cavendish was driven to the dire expedient of passing the current through his own body and estimating its magnitude by the intensity of the resulting shock! According to Sir Arthur Schuster the necessary apparatus was set up in the Laboratory and all visitors were required to submit themselves to the ordeal of impersonating a galvanometer. On one occasion a young American astronomer expressed his severe disappointment that after travelling to Cambridge on purpose to meet Maxwell and consult him on some astronomical topic he was almost compelled to take his coat off, plunge his hands into basins of water and submit himself to a series of electrical shocks!*

—ALEXANDER WOOD, *The Cavendish Laboratory.*

# NOTES AND DISCUSSION

## A Student Experiment with a Common A.C. Ammeter

W. H. ELLER
*Western Illinois State College, Macomb, Illinois*

IN some college courses the student encounters an electric circuit which carries both a.c. and d.c., and the question of how the combined currents will affect the reading of a common a.c. ammeter is to be answered. The common a.c. ammeter is the iron-vane type. Such a meter will read the *square root of the sum of the squares of the effective values* of the component currents. With a step-down transformer, a few dry cells, a resistance box, an a.c. milliammeter, and a d.c. milliammeter the student may easily demonstrate the truth of this law. The reason for this action, however, is not so easily shown. A numerical problem serves well to clarify the explanation.

When current flows through a meter of this kind the torque actuating the needle is due to the reaction between two magnetic fields, each of which is practically proportional in strength to the current producing it, provided the frequency is not too high. When the current reverses, the polarities of both fields reverse, resulting in a torque having the same sense as before reversal. Furthermore, since both fields are produced by the same current, the torque on the needle is proportional to the square of the current. Therefore, whether the current through the meter be a positive loop, a negative loop, a direct current, or a combination of these, the forward torque on the needle at any instant is proportional to the square of the current at that instant. In the case under consideration, the current is continually changing in amount, and, since the needle cannot follow these rapid changes, it is rotated, against the restoring torque of the spring, through an angle proportional to the average torque during the cycle. But this average torque is proportional to the average of the squares of the instantaneous values of current during the cycle. Therefore the deflection is proportional to the average of these squares, and the effective current is the square root of this average. To obtain the effective value, then, of a combination of currents, it is necessary to obtain the value of the current at each instant throughout the cycle, to square each of these values, to obtain the average of the sum of these squares, and then to take the square root of this average. The result is the root-mean-square value, abbreviated rms.

With simple arithmetic it is, of course, impossible to obtain the value of the current at every instant throughout the cycle, because there is an infinite number of possible values. A close approximation, however, may be obtained by using only eighteen values, spaced twenty degrees apart throughout one cycle.

The problem selected as an illustration involves an alternating current whose peak value is greater than the direct current component. If the circuit is of a kind in which the current can actually reverse and flow in the opposite sense, this reversal will really occur during a part of the negative loop. But during the time of this reversed current, the torque on the needle of this meter will still be in the forward direction and will aid in producing the net average forward torque. This type of circuit is assumed in the solution of the problem. However, if the current could not actually reverse, as in the plate circuit of an electronic tube, then the current would remain zero during a part of the negative loop, and this would reduce the meter reading. Its value could still be calculated by omitting those values of the total current which appear as negative in Table I.

The problem assumes a direct current of 30 ma combined with an alternating current $i$ of 40 ma (rms). The first column of Table I gives the angles at every 20 degrees throughout one cycle at which the instantaneous currents are calculated. Since zero is taken as the starting angle the last angle is 340 degrees, making 18 intervals of 20 degrees each. The second column gives the sines of the angles. Since a four-place sine table was used, no more than four significant figures were used in any factor or product. The third column gives the values of the alternating current component at these points in the cycle. These are obtained from the familiar relationships

$$i = I_0 \sin\theta \quad \text{and} \quad I = I_0/\sqrt{2}$$

where $i$ is the instantaneous current, $I_0$ is the peak current, and $I$ is the effective value as read by the meter.

The numbers in the fourth column of Table I are obtained by adding the 30 ma of d.c. to the instantaneous alternating current values in the preceding column. This fourth column, then, gives the total current at each 20-degree interval. The negative values mean that during this part of the cycle the current flows in the opposite sense in the circuit.

The fifth column gives the squares of the total currents and, therefore, these numbers show how the torque on the needle varies during the cycle. The average torque during the cycle, and also the deflection, is then propor-

TABLE I. Current values at twenty-degree intervals.

| $\theta$ degrees | $\sin\theta$ | $i$ (ma) | $i+30$ (ma) | $(i+30)^2$ (ma)$^2$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 30 | 900 |
| 20 | 0.3420 | 19.34 | 49.34 | 2434 |
| 40 | 0.6428 | 36.36 | 66.36 | 4404 |
| 60 | 0.8660 | 48.98 | 78.98 | 6238 |
| 80 | 0.9848 | 55.70 | 85.70 | 7344 |
| 100 | 0.9848 | 55.70 | 85.70 | 7344 |
| 120 | 0.8660 | 48.98 | 78.98 | 6238 |
| 140 | 0.6428 | 36.36 | 66.36 | 4404 |
| 160 | 0.3420 | 19.34 | 49.34 | 2434 |
| 180 | 0 | 0 | 30 | 900 |
| 200 | −0.3420 | −19.34 | 10.66 | 113 |
| 220 | −0.6428 | −36.36 | − 6.36 | 40 |
| 240 | −0.8660 | −48.98 | −18.98 | 360 |
| 260 | −0.9848 | −55.70 | −25.70 | 660 |
| 280 | −0.9848 | −55.70 | −25.70 | 660 |
| 300 | −0.8660 | −48.98 | −18.98 | 360 |
| 320 | −0.6428 | −36.36 | − 6.36 | 40 |
| 340 | −0.3420 | −19.34 | 10.66 | 113 |
| | | | | $\Sigma i^2 = 44986$ |
| | | | | $i_{Av}^2 = 2499$ |
| | | | | $I = 49.99$ ma |

tional to the average value of the numbers in this column. This average value is the sum of the numbers in the column divided by eighteen. Since this average is the square of the effective current, the effective current is given by the square root of this average.

The correct answer for this problem is 50 ma, obtained from the equation $I=(30^2+40^2)^{\frac{1}{2}}$, in accordance with the law that the effective current is the square root of the sum of the squares of the effective values of the component currents.

The calculations show that an answer of 49.99 ma is obtained. The difference, of course, is due to the facts that only eighteen points and only four significant figures were used.

## Elementary Proof of the Equation $v=(T/\lambda)^{\frac{1}{2}}$ for the Velocity of a Transverse Wave

Gustavo Villar Buceta
*Instituto de Pinar del Río, Cuba*

IN many textbooks of college physics, the equation in the title of this paper is deduced on the assumption of a translatory motion of a string, along which a wave travels, with a velocity opposite to that of the latter, so that the wave is considered as standing and the particles of the string are treated as moving along a curved trajectory and, accordingly, as subjected to a centripetal force which is identified with the resultant of tensions acting at the extremities of every element of the string. It cannot be denied that this reasoning is extremely artificial and involves a condition entirely foreign to the phenomenon. The author has used for many years, with the senior students of the above-mentioned *Instituto*—an educational institution comparable to a senior high school and junior college combined—the following method of deduction which requires nothing more than a knowledge of elementary mathematics.

Let $AB$ (Fig. 1) be an element, of infinitesimal length $s$, of a string stretched by a tension $T$, and let us call $\lambda$ the mass per unit length of the string, so that the mass of $AB$ is $m=\lambda s$. Assume that at a certain instant during the passage of the wave the element $AB$ is deformed to the arc $A'B'$, so that the displacements of $A$ and $B$ are $AA'$ and $BB'$, respectively, both displacements being perpendicular to $AB$, since the vibration of the string is supposed to be transverse. If we call $t$ the time interval in which the wave travels from $A$ to $B$ with velocity $v$, we may write $AB=vt$. At the end of interval $t$, $A'$ moves to $A''$ (such that $AA'=CC'$, $C'$ and $B'$ being symmetrical with respect to $AA'$) and $B'$ moves to $B''$ (such that $BB''=AA'$, provided the wave progresses to the right without deformation). The distance traveled by $A'$ in the time $t$ is $A'A''$, and if we call $a'$ the average acceleration of this point during that interval, we have $A'A''=a't^2/2$, provided $A'$ is a crest of the wave, in which case its initial velocity is zero. We have also $A''B'=AB=vt$.

Let us draw the normals at $A'$ and $B'$ to the curve $A'B'$, and let $O$ be the point at which they intersect and $\alpha$ the angle they form. If we draw the circle with center $O$ passing through $A'$ and $B'$, we have, by a well-known geometrical theorem involving the diameter $A'D$, $A''B'^2=A'A''\times A''D=A'A''(A'D-A'A'')$, and hence,

$$v^2t^2=(a't^2/2)(2R'-a't^2/2).$$

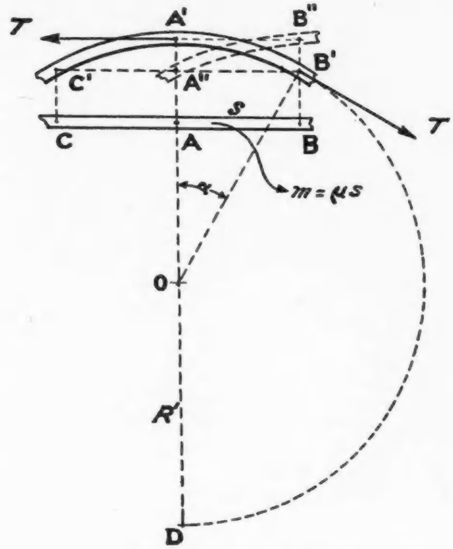


FIG. 1. Motion of an element of a stretched string along which a transverse wave is passing.

In this equation, $R'$ denotes the average radius of curvature of arc $A'B'$; and, after simplification, the last equality becomes $v^2=a'(2R'-a't^2/2)/2$.

The time interval $t$ is infinitesimal, and as $t$ approaches its limit, zero, $a'$ reaches the instantaneous value $a$, $R'$ becomes the radius of curvature $R$ at $A$, and the second term within the parentheses vanishes. Then

$$v^2=aR. \tag{1}$$

The force which causes $a$ is the resultant $F$ of the tensions $T$ acting oppositely (but not directly) at $A'$ and $B'$. We find $F$ by the rule of vector addition in Fig. 2, in which the angle $\alpha'$ is equal to $\alpha$ in Fig. 1. We have, therefore, in the limit, $F/T=s/R$, and hence $F=Ts/R$. Thus, we can write the acceleration in the form

$$a=F/m=T/(R\lambda), \tag{2}$$

whence, making use of Eq. (1), $v^2=T/\lambda$, from which the formula $v=(T/\lambda)^{\frac{1}{2}}$ follows at once.

It will be noticed that Eq. (2) is written under the same

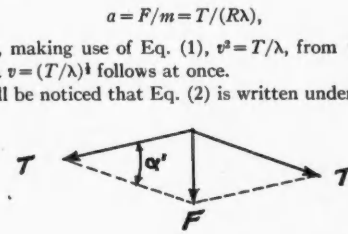


FIG. 2. The force acting on an element of the string is the resultant of two equal tensions not quite in exact opposition.

assumptions made in order to write the partial differential equation

$$\partial^2 y/\partial t^2 = (T/\lambda)(\partial^2 y/\partial x^2) \quad (3)$$

for the transverse motion of a stretched string, the derivative $\partial^2 y/\partial x^2$ being nothing else than an approximate expression of a curvature $1/R$, neglecting the assumedly small slope of the wave, or its exact expression at a crest of the wave. The pedagogical advantage of the deduction considered in this paper is the connection directly established between $v$, $T$, and $\lambda$, while the method of solution of Eq. (3) is too formal to allow the student to grasp that connection.

The author expresses his acknowledgment to those whose criticisms and suggestions contributed to improvement of the form of this paper.

## Fluxmeter Measurement of the Earth's Magnetic Field

D. S. Ainslie
*University of Toronto, Toronto, Ontario*

THE method described in this paper is a modification of the standard method employing an earth inductor coil in series with a ballistic galvanometer. In place of a galvanometer a portable fluxmeter is used in conjunction with special low resistance earth-inductor coils.

Two coils were constructed for this work, one circular and the other rectangular in shape. The latter coil consisted of a rectangular wooden frame approximately 27 cm×34 cm with the central axis of rotation parallel to the shorter side of the coil. It was mounted on a wooden frame which could be set with the axis of rotation either vertical or horizontal. A shallow groove 3.5 cm wide was cut around the outer perimeter of the coil and into this, a two-layer coil of 122 turns of No. 20 enameled copper wire was wound. The resistance of the coil was measured as 12.5 ohms at 24°C. The area of the turns in the coil was considered as the average of two estimates, one made from measurements secured while winding coil and the other from the electrical resistance of the coil. The value of this area $A$ was estimated as 914 cm². The number of turns $N$ is 122. Hence $NA = 1.115\times 10^5$ cm².

The circular coil consisted of 490 turns of No. 20 enameled copper wire in a groove, 2 cm×2 cm on the outer circumference of a circular frame with an outside diameter of 26.5 cm. The resistance of the coil was 12.4 ohms at 26°C. Because of the large number of layers of wire on the coil no attempt was made to measure the area $A$ directly. The value of the product of turns multiplied by area was determined indirectly from measurements made at the magnetic station at Agincourt.

For any coil rotated through an angle of 180° about an axis perpendicular to a field $H$ the change of flux density equals $2H$ with the initial and final positions perpendicular to the field $H$. With this coil connected to the fluxmeter used in these tests for which the sensitivity is 5000 maxwells for a single turn

$$2HNA = 5000\theta$$

or

$$NA = 5000\theta/2H.$$

The value of $\theta$ the fluxmeter deflection was determined from the average of a set of measurements made at Agincourt. For each determination ten or more observations were made with the swing of the fluxmeter alternating in direction as the coil was turned over in one direction and then returned to its original position. For each observation the fluxmeter deflection was taken as the difference of two readings without returning the needle to the zero position in each case. The external resistance was made up to 15 ohms for each measurement by connecting a small resistance in series with the coil and the fluxmeter. An average deflection of 49.93 divisions was evaluated for the fluxmeter deflection corresponding to the vertical component $H_v$ of the earth's magnetic field. The listed value for Agincourt to 3 significant figures is 0.562 cgs units. Hence for the circular coil

$$NA = (49.93)(5000)/2\times 0.562 = 2.221\times 10^5 \text{ cm}^2.$$

The corresponding equation for the measurement of any magnetic field $H$ is

$$H = \sigma.01125\theta.$$

Groups of measurements were carried out in the laboratory at Toronto using both the coils and also two fluxmeters labeled No. 1 and No. 2, respectively. The fluxmeters were similar instruments[1] with the same calibration of 5000 maxwells per division for a single turn coil. In each case the determinations made with fluxmeter No. 2 are lower than the corresponding measurements with fluxmeter No. 1. For accurate work this source of error could be eliminated by making independent calibrations for each fluxmeter. It was found essential to take a group of readings for any one measurement as the fluxmeter needle showed a tendency to creep back slowly in the reverse direction after each deflection. Within fairly wide limits the deflections secured were independent of the speed of rotation of the coil and hence no special device was required to rotate the coils. The average values obtained were: for $H_v$, 0.548 cgs units; for $H_h$, 0.187 cgs units; for angle of dip, 71°12′.

For comparison purposes the value of $H_h$ was measured by Shuster's method[2] employing a tangent galvanometer and the angle of dip was measured by means of a dip needle. The values obtained were 0.186 cgs units and 71°53′.

While the accuracy obtained by means of the fluxmeter is not as high as that secured with a ballistic galvanometer, this method is useful for certain routine laboratory measurements in that the equipment is portable and the calculations involved are comparatively simple.

[1] Sensitive Research Instrument Company's models FS and FM.
[2] Das, *Electricity* (Van Nostrand, ed. 1, 1948), pp. 133–134.

## A Demonstration of Electron Paths Perpendicular to a Magnetic Field

R. Stuart Mackay
*University of California, Berkeley 4, California*

THERE have been several excellent suggestions for devices for demonstrating the trajectories of electrons in magnetic fields. Most of these devices use a vapor

not only to make the electron paths visible through excitation, but also to maintain collimation through the formation of positive ion sheaths. It is unfortunate that many institutions do not have the facilities to perform the required glass blowing and evacuation, since a graphic demonstration of the motion of electrons in certain simple field configurations is highly desirable. The following experiment uses only materials readily accessible to all, and it illustrates rather well the most fundamental case, i.e., the path of electrons moving perpendicular to a magnetic field. It is a particularly apt demonstration of the processes going on in a classical magnetron, though admittedly certain details are lacking. The experiment, since it is on a small scale, is best suited to small discussion groups or to a laboratory demonstration, but even in lecture sections of fifty or more, it can be readily seen if rotated to face different parts of the class.

The basic element is an electron-ray tube known as a *tuning eye*. In ordinary use, a shadow of variable angular width is cast on a fluorescent anode to indicate the potential to which some parameter has placed the shadow-casting electrode. The anode is essentially a truncated cone with the large diameter facing out, and along the axis of which is placed the filament. A small piece of metal parallel to this cathode casts a shadow if its potential is less than that of the anode. Since the electrons tend to move approximately radially outward, and since their position is sampled by the sloping anode at different distances from the cathode, when the tube is placed in an axial magnetic field this shadow will trace out a curved path because of the curved paths followed by its marginal electrons.

However, a modified form of this basic idea makes possible a much more polished demonstration. One eye-tube numbered 6AFG has two shadow-casting electrodes in order that two diametrically opposite shadows may be obtained. As here used, these shadows are made much wider than usual by the application of a large negative voltage to the control electrodes. Each shadow is opened up to just a little under 180 degrees so that the total emission lies in two diametrically opposite radial sheets parallel to the axis. When the tube is viewed from the end one sees two green lines running from the cathode to the periphery of the circular anode (Fig. 1). These lines can be

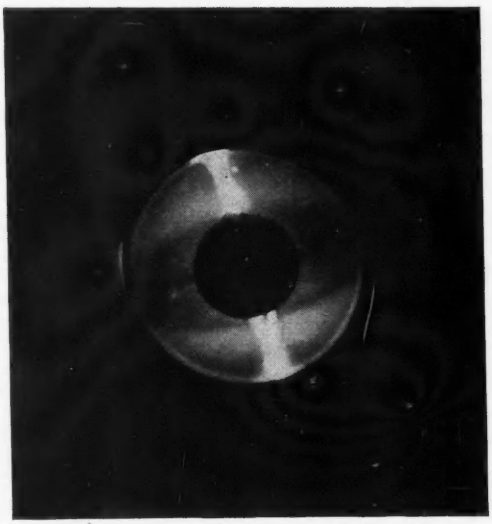

FIG. 1. Prior to the application of a magnetic field, a long exposure shows tube details.

FIG. 2. Curvature produced by a weak axial field.

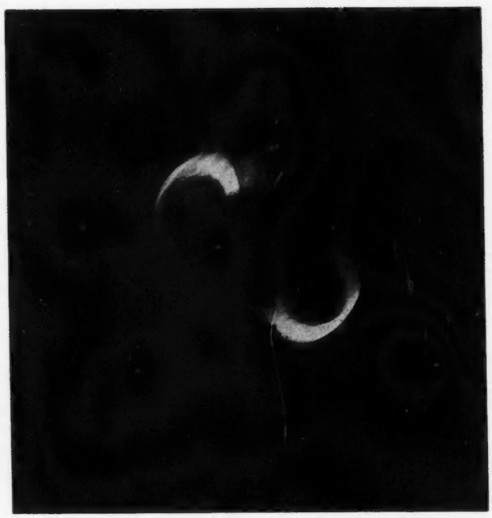

FIG. 3. The condition of a magnetron on the verge of cut-off.

FIG. 4. A strong field in which no electrons would reach the anode of a magnetron.

considered as the paths of typical electrons in a magnetron before the magnetic field is applied. If an axial magnetic field is now applied, the electron paths curve in a very satisfactory manner as shown in Figs. 2 and 3. When the "magnetron" passes cut-off (Fig. 4) one apparently sees the return paths of electrons that have missed the anode and are returning to the cathode. Although apparent cut-off makes the demonstration appear more realistic, due to the radial sampling process going on at different axial levels in the sheet of electrons, true cut-off cannot occur. Probably the appearance is due to electrons in the higher levels of the tube being pulled toward the base of the tube and into the sloping anode. This explanation seems reasonable since, due to the sloping of the anode, the radial electric field is not equally strong at all levels and thus the resultant electric field has a component toward the base of the tube.

The electronic circuit (Fig. 5) required to run the tube is quite simple. A full wave voltage doubler using a pair of selenium rectifiers is used since it conveniently supplies both plus and minus 150 volts relative to a readily accessible point. Since intermittently used electrolytic condensers sometimes become leaky and thus discharge themselves, a standard twenty-ohm surge-limiting resistor is included in the circuit, even though the current demands of the tube are very small. The full negative 150 volts is applied to the control electrode, but it should be noticed that the positive anode voltage is somewhat reduced by the insertion of a 65,000-ohm resistor. Though this slightly reduces the beam intensity, it makes the green lines narrower and also increases contrast by cutting down a

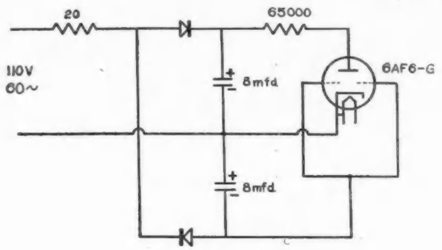


FIG. 5. The circuit to operate the electron-ray tube.

background of electrons that tends to fall in the shadow area.

A solenoid such as the coil from an old filter choke is quite suitable for producing the axial magnetic field, although in some cases it may be more convenient to use a hollow cylindrical permanent magnet such as is used for the field of some loud speakers. A strong magnetic field will produce a pair of small closed curves that rather closely resemble circles. Thus, the path of electrons moving perpendicular to a magnetic field alone is more closely portrayed than the detailed motion is a magnetron, but the general type effect in the latter is well displayed.

AMERICAN JOURNAL OF PHYSICS VOLUME 17, NUMBER 7 OCTOBER, 1949

# LETTERS TO THE EDITOR

## Color Effect of Fluorescent Lighting

THE color effect that may be seen by examining many light sources by means of a stroboscope is well known to those working in the field of illumination. However, except for the few familiar with this field of work, the effect is not generally known. The *color flicker* may be readily observed by spinning a coin under a fluorescent lamp. Here, fringes are observed which appear either yellow or orange, depending on the background upon which the spinning coin is viewed. On a white surface the fringes appear yellow, but on a dark surface, such as green, they appear orange because of the eye's compensation. More accurate observations by stroboscopic means at different phases of the lighting cycle indicate that the yellow color is due to the persistent glow of the fluorescent coating of the tube when the voltage is passing through zero. The color of the observed phosphorescence is of course, characteristic of the particular fluorescent powder used in a lamp.

GEORGE E. HAUVER

*University of Maryland,*
*College Park, Maryland*

## The Behavior of a Carbon-Filament Lamp in a Magnetic Field when Energized with (a) Alternating Current (b) Direct Current

EXPERIMENT E-139 in Sutton's *Demonstration Experiments in Physics* is designed to show the vibration of a lamp filament carrying alternating current when a magnetic field is impressed. This demonstration has greater pedagogical value if the experiment is shown with both alternating and direct current.

With a.c. and a strong Alnico horseshoe magnet, one loop of the filament can be put into vigorous vibration so that mechanical resonance is achieved. It is an easy matter to establish sufficient amplitude to destroy the filament. If the horseshoe magnet is set symmetrically astride the globe, both loops of the filament may be made to execute patterns of vibration not unlike Lissajous figures. The effects can be shown at 25 c/sec and at 60 c/sec, and some generalizations drawn. At 25 c/sec the effects are more pronounced and maximum amplitude is acquired sooner than at 60 c/sec. In addition, a very remarkable thing occurs at the points where the filament emerges from the glass support. With one orientation of the magnet astride the lamp, arcing takes place from one lead to the middle wire support. If the poles are reversed, arcing takes place from the *other* lead to the middle wire support! This detail is not easily disposed of!

With d.c. a most interesting array of observations are to be made.

(1) Set the horseshoe magnet symmetrically astride the globe. The two loops of the filament *spread far apart.*
(2) Reverse the position of the poles. The two loops *move closer together.*
(3) Turn the magnet around (rotate on a vertical axis); a torque is set up which produces a substantial *twist* in the filaments.
(4) At some intermediate position of the poles no displacement of the loops is observed.
(5) When *one* pole is brought close to the top of the lamp and then gradually brought down over the side, a loop of the filament may be so displaced as to bring it into contact with the glass walls of the lamp. It is then instantly fused to the glass. If it does not promptly break, the glass is shortly melted through.

All of these observations, particularly those with d.c., are excellent exercises for classroom discussion of the left-hand rule.

JULIUS SUMNER MILLER
*Michigan College of Mining and Technology, Sault Ste. Marie, Michigan*

## An Extension of a Simple Experiment Designed to Show the Heat Generated by a Spark

THE demonstration experiment E-54 in *Demonstration Experiments in Physics* by Sutton is designed to show the heat generated by a spark. A modification of the experiment shows some interesting and instructive aspects.

An exhaustion flask has attached to its side-arm an oil manometer. A two-hole stopper fitted tightly is provided with two electrodes energized by an induction coil or static machine. When a spark is passed the manometer shows *immediately* an increase in pressure due, obviously, to the heat generated by the spark. If the sparking is stopped after running several seconds the manometer returns *quite immediately* to its equilibrium position and then *more gradually* to a lower level on the atmospheric side. This last observation is not usually made and only close watching reveals the drop in pressure within the flask. If a horizontally-ruled scale is provided the manometer fluctuations can be more easily followed.

As a demonstration the class can easily account for the pressure rise but the pressure diminution is much less understood. The following appears to account for it:

$$N_2+O_2\rightarrow 2NO$$
$$2NO+O_2\rightarrow 2NO_2.$$

The first equation is simple nitrogen fixation; the second shows a decrease in the number of molecules. It is not unlikely that $O_3$ also results and aids the pressure diminution by a factor of 3:2.

JULIUS SUMNER MILLER
*Michigan College of Mining and Technology, Sault Ste. Marie, Michigan*

## Physics in Motion Pictures

ROGER ALBRIGHT, Educational Director for the Motion Picture Association of America discussed with some of our staff the policies of his Association in excerpting films for use in educational institutions. Briefly, the Motion Picture Association stands ready to co-operate with an organization like the American Association of Physics Teachers in making existing theatrical (or Hollywood) films available to schools and to film libraries in excerpted form, provided they can be rather widely used in some subject matter field. The organization representing the field must be able to supply a committee which will supply technical advice on content and aid in previewing and excerpting. The Motion Picture Association will supply travel and hotel expense of the committee, and all of the technological work to make a complete, usable picture. You may have seen some of their films such as the school versions of "Tale of Two Cities" or "David Copperfield," each lasting 50 minutes and on 16 mm film.

So far nothing has been done in the field of physics. Nothing will be done unless an organization such as the AAPT asks an opportunity to work with the Motion Picture Association on a co-operative basis. The organization should have some definite ideas of films which it would like and that would be generally accepted. Please note that the Motion Picture Association won't produce anything new, but will supply almost any footage of film which has already been taken so that it can be combined to form the film the co-operating organization would want. The Motion Picture Association would supply titles

cutting, music, and other necessary details to make the film useful.

Before the AAPT expresses itself on this matter, there should be an exploration of the possibilities and needs in physics. I can think of some films which I believe could be so produced and would fill a need:

1. A film tracing the development of the sciences—(aimed at whatever the group might want, but preferably encouraging respect for the work of ancients, astrologers, philosophers, inventors, etc., indicating errors in thought and method, and showing the major milestones in method together with the accompanying ever more rapid extension of knowledge).
2. A film excerpting "Madame Curie," probably a 50 minute film.
3. Possibly some short films (12–24 minutes) on Roentgen, Pasteur, and others, or some recent advances in our field which have been portrayed in news reels, March of Time, or in segments of feature films. (In a number of cases a 3 to 5 minute relief is provided in a dramatic film, which, taken out of context, is almost wholly suitable to school needs. It must present a fairly complete story so that it may be usable as a segment in its original film.)

The purpose of this letter is first to explore the interest our association might have in such a project, and second to ask for sections of films which members may have seen which might be useful in the high school or college physics classroom. The most important questions are these: Do you believe the American Association of Physics Teachers should interest itself in this as a project? If you believe that it might undertake such a job, do you have suggestions of films or segments of films which might be suitable? Do you recall any film which portrays segments of the life and work of some physical scientist? Would any segments of the films on Alexander Graham Bell or Edison be usable? Do you recall any picturization of Galileo which has segments which could be excerpted? Can't we get a film which will be a powerful aid in helping instill the attitudes which we all have as teaching objectives?

ALFRED B. BUTLER

*The State College of Washington,*
*Pullman, Washington*

*In order that the interest of AAPT members may be estimated readers are requested to send their comments and suggestions as to useful segments of films directly to Professor Butler.*—EDITOR.

## Electric Discharge in Air at Reduced Pressure

IN preparing a long glass tube for showing discharge-in-vacuo phenomena, I found it necessary to use two long iron spikes (sealed into cork stoppers) for the electrodes. At a few centimeters of mercury the usual wavy streamers were observed and on further reduction of pressure the familiar characteristics of a glow discharge appeared, such as the Crookes' dark space and the positive column, with the striations fairly concave toward the anode. *What I did not observe, however, was the Faraday dark space,* that region next to the negative glow where the light intensity diminishes to practically zero.

It is well known that the glow characteristics depend in large part on the potential gradient in the cathode dark space and it has been shown (by means of probes and exploring electrodes) that a *large* potential drop occurs in the cathode dark space. It is also known that the cathode dark space is a region of high positive space charge and that the concentration falls off in the Faraday dark space.

*Now all these observations are made on a glass tube equipped with two metal circular plates as electrodes.* I wish to suggest in this note that a vastly different electrical state exists in a tube equipped with *pointed* electrodes. In particular, the Faraday dark space appears *not to develop.*

I intend to look into this further, both theoretically and experimentally, but perhaps this letter will lead to some interesting speculation.

JULIUS SUMNER MILLER

*Michigan College of Mining and Technology,*
*Sault Ste. Marie Branch,*
*Sault Ste. Marie, Michigan*

## When is the Sine of an Angle Equal to the Angle?

NUMEROUS derivations and problems are simplified by the assumption that the angle is so small that its sine is practically equal to the angle, in radians. However, many students do not visualize the situation clearly enough to appreciate the extent of the approximation. The two curves shown herewith in Fig. 1 represent an attempt to

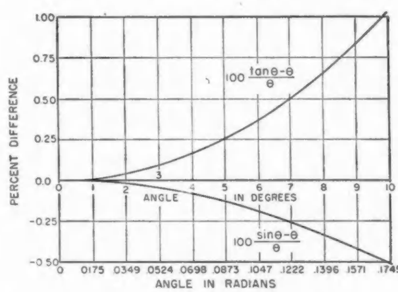


FIG. 1. Approximations involved in using the angle in place of its sine or tangent.

make matters clearer. They show that there is justification for the statement that up to ten degrees the error in using $\theta$ in place of $\tan\theta$ is less than one percent, and less than one-half percent in case of the sine.

Perhaps it would help some students if they would recall the series expressions for the tangent and the sine, whereupon the approximation

$$\theta = (2\sin\theta + \tan\theta)/3$$

is seen to be very good indeed for angles less than ten degrees, and often adequate at larger angles.

H. W. FARWELL

*Columbia University,*
*New York 27, New York*

## Diffraction by Two Noncoplanar Obstacles

In a recent article under the above title, Ellis[1] proposed to explain an anomalous behavior of the shadows cast in sunlight by two obstacles at different distances from the sun as a diffraction effect, basing his conclusion on similarities between the shadows and the diffraction patterns of noncoplanar obstacles. The shadow effect is as follows: If two obstacles at different distances from the sun move in a direction at right angles to the sun's rays so as to decrease the distance between their shadows, one of the shadows starts to bulge toward the other, the shadow of the object which is more remote from the sun and hence closer to the viewing screen always being the one which bulges. It is difficult to see how this could be a diffraction effect, in view of the finite size of the sun. On the contrary, it would seem that the correct explanation lies in the fact that the sun does have finite size.

If an object is sufficiently close to the viewing screen, its shadow in sunlight consists of an umbra and a penumbra, and the width of the penumbra depends upon the distance from the obstacle to the screen, being smaller the closer the object is to the screen. In Fig. 1 the solid curves are

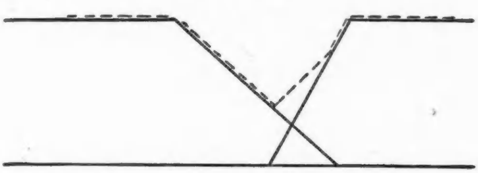

FIG. 1. Overlapping of two penumbras.

plots of the amount of light from the sun intercepted by each of two obstacles acting alone, at varying positions on a viewing screen. The curve on the right is for the object which is closer to the screen. The figure is drawn as if the sun were square, for simplicity. When the penumbras partially overlap, as in the figure, the dotted curve shows the actual interception of the light. One observes that it is the right-hand shadow which appears to be affected.

H. A. NYE

*University of Buffalo,*
*Buffalo, New York*

[1] C. F. Ellis, *Am. J. Physics* **16**, 8 (1948).

## Interpretation of the Poisson Brackets

The physical interpretation of the Poisson brackets does not draw much attention in the study of analytical mechanics. As a consequence, the appearance of these symbols in the basic commutation law of quantum mechanics is generally received as a mathematical device of unclear significance. It may then be of some interest to stress here a physical interpretation of Poisson brackets which bears directly upon the role they play in quantum mechanics.

Consider a Hamiltonian system, that is a physical system described by a set of coordinates $q_k$ and of their canonically conjugate momenta $p_k$. When two physical quantities $F$ and $G$ are defined as functions of the $q_k$'s and $p_k$'s, their Poisson bracket is defined as:

$$[F, G]=\Sigma_k\left(\frac{\partial F}{\partial q_k}\frac{\partial G}{\partial p_k}-\frac{\partial F}{\partial p_k}\frac{\partial G}{\partial q_k}\right). \tag{1}$$

In the particular case where $F$ is simply one of the coordinates, say $q_r$, Eq. (1) reduces to the well-known formula:

$$[q_r, G]=\partial G/\partial p_r. \tag{2}$$

Now any quantity $F$ can be considered as the coordinate $Q_1$ of some new system of coordinates related to the previous one by a contact transformation. Since the Hamiltonian form of the system is preserved by this transformation, there will be a momentum canonically conjugated to $Q_1=F$ in this new system; this momentum will be indicated as $P_1$ or $P_F$. Equation (2) yields then:

$$[F, G]=\partial G/\partial P_F. \tag{1'}$$

A better physical understanding would probably result if we take Eq. (1′) as the primary definition of the Poisson bracket. According to this definition the bracket appears to be an index of whether, and how much a quantity $G$ depends on the momentum $P_F$ canonically conjugated to the quantity $F$. Equation (1) represents then the analytical expression of this index in terms of a general system of coordinates.

It is interesting that the momentum $P_F$ canonically conjugate to a quantity $F$ is not uniquely defined unless the entire system of coordinates $Q_r$, $P_r$, of which $F=Q_1$ and $P_F=P_1$ are elements, is adequately specified. However, the derivative $\partial G/\partial P_1$ will have the same value independently of the detailed choice of the other coordinates. To verify this, one can compare different systems of coordinates, orthogonal and nonorthogonal.

When studying the commutation law of operators in quantum mechanics one may establish first the law for the operators associated with canonically conjugate quantities:

$$q_rp_r-p_rq_r=i\hbar.$$

Since all the nonconjugate pairs of elements of the system $q_k$, $p_k$ commute freely, it seems reasonable that the value of the commutator $q_rG-Gq_r$ will be determined by the dependence of $G$ on $p_r$. This argument leads to the formula:

$$q_rG-Gq_r=i\hbar\partial G/\partial p_r, \tag{3}$$

which can be proved for a large class of functions $G(q_k, p_k)$.[1] The arguments previously applied to the discussion of the Poisson brackets lead then directly to the general law:

$$FG-GF=i\hbar\partial G/\partial P_F=i\hbar[F, G]. \tag{3'}$$

The equality of the first and last of these expressions is frequently introduced as a postulate, without much attempt to illustrate its significance. A better understanding should result if we add the intermediate expression $i\hbar\partial G/\partial P_F$, that is, if we consider Eq. (3′) as a combination of Eqs. (1′) and (3).

U. FANO

*National Bureau of Standards,*
*Washington, D. C.*

[1] See, for example, W. Pauli in Geiger-Scheel, *Handbuch der Physik* (Springer, Berlin 1933), bd. **24/2**, p. 118.

## Maxwell's Relations Again

I HAVE read with interest the letters regarding various mnemonic devices for remembering the general relations of Maxwell for a system under uniform hydrostatic pressure,[1] and agree entirely with Professor Brinkman[2] that attempts to remember these relations are both unnecessary and undesirable when they can be so readily deduced from fundamental principles.

I would, however, go farther than Professor Brinkman and insist, except for special relations in which the enthalpy $H$, $(U+pV)$, Helmholtz's free energy $A$, $(U-TS)$, and Gibbs' potential $G$, $(U-TS+pV)$ are needed *as such*, that not only all of the standard forms of Maxwell's equations but also all the other general thermodynamic relations (not involving $U$, $H$, $A$, or $G$ specifically) may be obtained in a direct and unambiguous way, from any *single one* of the usual differential expressions given below. As a consequence we need only remember *one*, say that for $dU$, and the rest follow from this so directly that they may be written down as wanted. This result follows from two Jacobian theorems of a general nature which I have called attention to in a paper in this Journal[3]—theorems whose utility and conciseness arise from the general properties of Jacobians.

If we write

$$dU=TdS-pdV, \tag{1}$$

$$dH=TdS+Vdp, \tag{2}$$

$$dA=-SdT-pdV, \tag{3}$$

$$dG=-SdT+Vdp, \tag{4}$$

the first theorem states that if we have an exact differential, say $dU$, of a function of two variables, then the condition of *exactness* expressed in terms of any arbitrary pair of new variables $(x, y)$, which may or may not appear in Eq. (1), is conveniently written as

$$\frac{\partial(T,S)}{\partial(x,y)}-\frac{\partial(p,V)}{\partial(x,y)}=0=J(T,S)-J(p,V), \tag{5}$$

where the numerators of the Jacobians involved always have the variables occurring in the *right* of the expression for $dU$ in the conjugate pairs in which they appear and in the order there given. If we apply the same theorem to $dH$ we have $J(T,S)+J(V,p)=J(T,S)-J(p,V)=0$, since changing the order of two *dependent* variables (or independent variables for that matter) in a Jacobian merely reverses the sign. But this is Eq. (5) again. Likewise from $dA$ we have $-J(S,T)-J(p,V)=0$, which on reversing the order in $J(S,T)$ reduces to the same expression. A similar result follows from $dG$ where the order in each Jacobian needs reversing. Thus we may obtain the six different (and equivalent) forms of Maxwell's relations by letting $(x, y)$ be in turn the six different pairs of variables we may select from the set $(T, S, p, V)$. We may start with any of the Eqs. (1) to (4), since from this standpoint they are equivalent. This is a result which we should expect, of course, since Eqs. (2), (3), and (4) may be obtained in turn by subjecting $dU$ to a *Legendre* transformation. The above analysis, however, brings the equivalence to light in a clearer way than any other I know.

The second theorem mentioned above may be stated in a new and more convenient manner as follows:[4]

If we allow $(x, y)$ to be *nonconjugate* variables, chosen from the right of any of the Eqs. (1) to (4), then the *fundamental* Jacobian, $J_0$, is defined as

$$J_0\equiv\frac{\partial(X,Y)}{\partial(x,y)},$$

where $(X, Y)$ are the dependent variables left after $(x, y)$ are chosen. Then it follows that $J_0$ is (1) *symmetric* about the positive diagonal and (2) contains all the *derivatives* needed for calculating any other desired *first* derivation whatever.

A rule of signs must be followed in writing down $J_0$ which may be best illustrated by two examples.

*Case (a):* Let $(x, y)$ be $(T, p)$ in Eq. (1). Then $(X, Y)$ is $(S, -V)$, the minus sign arising from that of the term $pdV$. Then

$$J_0\equiv\frac{\partial(S,-V)}{\partial(T,p)}=\begin{vmatrix}\dfrac{\partial S}{\partial T} & -\dfrac{\partial V}{\partial T}\\[2ex] \dfrac{\partial S}{\partial p} & -\dfrac{\partial V}{\partial p}\end{vmatrix},$$

and since this is *symmetric*, $(\partial S/\partial p)_T=-(\partial V/\partial T)_p$, which is Maxwell's relation for this choice of $(x, y)$. Any other derivative whatever may be expressed in terms which will involve *only* at most three of the four derivatives in $J_0$.

*Case (b):* Again choose $(x, y)$ as $(T, V)$ and, therefore, $(X, Y)$ as $[S, -(-p)]$ or $(S, p)$, where the two minus signs arising before $p$ cancel each other (the first coming from the sign of $pdV$ and the second needed because in selecting $(x, y)$ we chose $T$ from $TdS$ but reversed the order and chose $V$ from $pdV$). Then for this case

$$J_0\equiv\frac{\partial(S,p)}{\partial(T,V)}=\begin{vmatrix}\dfrac{\partial S}{\partial T} & \dfrac{\partial p}{\partial T}\\[2ex] \dfrac{\partial S}{\partial V} & \dfrac{\partial p}{\partial V}\end{vmatrix}.$$

Since this too is a *symmetric* determinant, equating the terms off the main diagonal gives us Maxwell's relation for *this* choice of independent variables, etc. There are two remaining choices of *nonconjugate* independent variables $(x, y)$, *viz.*, $(S, p)$ and $(S, V)$. For these cases we have $J_0(T,V)\equiv\partial(T,V)/\partial(S,p)$ and $J_0(T,-p)\equiv\partial(T,-p)/\partial(S,V)$, respectively. For the two *conjugate* choices of $(x, y)$, *viz.*, $(T, S)$ and $(p, V)$, $J_0$ is no longer a symmetric determinant.

The general $n$-variable theorems, of which the above are special cases for $n=2$, are discussed in detail elsewhere[5]—this letter is intended simply as an indication of the unification of methods which the Jacobian treatment permits.

F. H. Crawford

*Williams College,*
*Williamstown, Massachusetts*

[1] C. M. Focken, *Am. J. Physics* **16**, 450 (1948). W. E. Haisley and J. Bugosh, *ibid.* **17**, 91 (1949).
[2] H. C. Brinkman, *Am. J. Physics* **17**, 170 (1949).
[3] F. H. Crawford, *Am. J. Physics* **17**, 1–5 (1949). Saha and Srivastava, *A textbook of heat* (Allahabad, 1931), p. 408, ff.
[4] F. H. Crawford, *Physical Rev.* **76**, 456 (1949).
[5] Part I submitted for publication in *Proc. Am. Acad. Arts Sci.*, Part II (Variable Mass Systems) in preparation.

## The Delusion of the Scientific Method

I FIND a good deal to disagree with in the article "The delusion of the scientific method" by Haym Kruglak (*Am. J. Physics* **17**, 23 (1949)), as well as some points of agreement. Principally I object to his contention that there is no real, unique meaning to the term "scientific method."

Of course there are many scientific methods in the sense that Kruglak implies, although I think a better terminology for what he refers to might be "scientific techniques." In another sense—the more usual sense—there certainly is a unique "scientific method," as I shall attempt to show. In doing so, I feel almost guilty of plagiarism in repeating what has doubtless been stated many times before, and probably more effectively; yet it seems necessary to do it.

The assertion that there is such a thing as a scientific method implies that there is also an unscientific method; and, of course, there is. It consists of drawing inferences from unnecessarily limited observations, of being very uncritical of the reliability of data and the admissibility of evidence, and of reaching conclusions without subjecting inferences to extensive tests by experiment or by comparing for compatibility with known facts.

The scientific method is simply a more highly refined process which recognizes the risk of error inherent in the unscientific one. By being much more cautious about drawing inferences, much more critical of the validity of data, and by subjecting inferences (hypotheses) to exhaustive experimental tests and theoretical analysis before reaching even tentative conclusions (theories), the genuine scientist raises to a high degree the probability that his conclusions (if any) are *reliable*.

This statement defines what might be called the elements, or basic principles, of the scientific method, which may now be defined merely as the systematic or organized process of obtaining useful knowledge (of any kind whatsoever) by observing these principles. There are, of course, other less basic characteristics of the process; I believe that I have listed the truly fundamental ones.

It may also be remarked, probably for at least the millionth time, that there are some matters on which we would like to have reliable knowledge but which are, at least for the present, not susceptible to attack by the scientific method. However, the subjects to which this statement applies are not nearly as numerous, in my opinion, as some scientists contend.

The definition of "the scientific method" is as simple as this, and is not a delusion. It is true, of course, that more than the simple observance of these principles is required for one to be a brilliant scientist, or even a highly successful one. Unfortunately, it seems that one must also have inborn mental ability of a high order. But one might quarrel, nevertheless, with Kruglak's assertion that "The scientific method is no guarantee that the user, however expert, . . . will not draw the wrong conclusions." It does just exactly that; in a practical sense, it insures against wrong conclusions—that is, it renders them highly improbable. That, I believe, is the secret of its astonishing successes; the failures are not due to the method, but to imperfect application of it.

It must be emphasized that the foregoing refers to *conclusions*—not to hypotheses, which every good scientist knows must often turn out to be wrong. It must also be realized that insuring that *wrong* conclusions *will not* be reached is quite different from a guarantee that the *correct* conclusions *will* be reached—the latter achievement, as I have already implied, depends largely on mental ability and other personal factors.

Finally, to forestall quibbling, one must be cautious about the use of the word "wrong." There is a lot of nonsense about "the meaning of truth," on which, of course, the definition of "wrong" depends. Perhaps it is sufficient to point out here, with apologies to the majority of readers, that when a scientific law is superseded by a more comprehensive one, the earlier "law" is not thereby proved wrong, or untrue—it is merely shown to be not the whole truth, or only conditionally true—usually a "special case" of the more comprehensive law, which itself may in turn be supplanted later on by some still more general truth.

LAMONT V. BLAKE

*1308 45th Place S.E.*
*Washington 19, D. C.*

## The Delusion of the Scientific Method

IN my article I have probably overemphasized the negative aspects of the issue.

No one can survey the development of the sciences without realizing that there must be *something*, some complex of elements, which enters into the solution of a problem.

It has been my intention to point up the dangerous pedagogical implications which result from an oversimplification of what many believe to be a highly complex series of processes—the scientific method. The method itself is not a delusion; otherwise our efforts as science educators would be pointless.

One cannot quarrel with a logical definition, and Mr. Blake's is a careful one, but the difficulty arises when one attempts to bring such a definition into a sharp operational focus.

What is needed is a tremendous amount of research on the "elements" of the scientific method and on the "inborn mental ability of a higher order." Must we continue to rely on opinion, debate and discussion? Is it possible that the scientific method is *inapplicable* to the investigation of its own nature? Have we really tried investigating it?

The other day I asked a prominent scientist at the University of Minnesota: "Can you define the scientific method?" He replied: "Goodness, no! But I hope I use it!"

H. KRUGLAK

*University of Minnesota*
*Minneapolis, Minnesota*

## The Dimensions of Physical Concepts

IN a recent paper by P. Moon and D. E. Spencer,[1] an an outline is given of the use of a non-Euclidean space, and two length concepts are proposed ($L_r$ and $L_t$) as sub-

stitutes for the usual single length concept ($L$) in order to eliminate present ambiguities in dimensional analysis.

I should respectfully like to point out that the attempt to use two primary lengths is not new. A perusal of the literature shows that the proposal recurs with fair regularity. For example, Starling[2] mentioned the possibility of the use of $L_x$ and $L_y$ to enable one to assign a dimension to the angle concept.

There is a question as to whether one can ever successfully use two or more fundamental space concepts, such as the authors' $L_r$ and $L_t$. Buckingham[3] in his discussion on complete physical equations, stated: "Such expressions as log $Q$ or sin $Q$ do not occur in physical equations; for no purely arithmetical operator, except a simple numerical multiplier, can be applied to an operand which is not itself a dimensionless number, because we cannot assign any definite meaning to the result of such an operation."

At present we can use arithmetical operators because we have defined concepts such as angle so that they will be dimensionless. Whenever we define a ratio, $L_r/L_t$ say, so that the ratio has dimensionality, then by Buckingham's statement we are barred from operating on the ratio by sin, log, etc.

It is worth noting that this writer does not say that we cannot define fundamental concepts as we please. But he does maintain that, unless we define our concepts so that they are consistent with the rest of dimensional analysis and obey whatever mathematical laws we choose to set up, then our definitions are of little utility.

The authors' use of $L_r$ and $L_t$ to eliminate the ambiguity between energy and torque would certainly be helpful, except that such use appears to raise more problems than it solves. How, for example, would one distinguish (idonically) between the concepts of the kinetic and potential energy of an object raised to a height, $h$, above the earth and permitted to fall freely under the influence of the earth's gravity alone? Obviously all of the length concepts in both energies are radial, so that there is no way one can distinguish between the two energies when they are expressed in terms of $L_r$, $L_t$, $m$, $t$, dimensions. Yet, it is universally agreed that kinetic and potential energies are separate concepts just as much as are energy and torque.

Any investigator who is able to reorganize dimensional analysis concepts *consistently* so as to enable us to prove Buckingham's statement wrong, will have performed a far greater service than merely removing ambiguities. Such reorganization would permit us to set up the differential equations of a system by routine operations on dimensionless $\Pi$'s (as this writer has been attempting, very unsuccessfully, for several years) without detailed knowledge of the physics of the situation. For specific cases, Hersey[4] solved part of the problem, i.e., where one partial derivative is known, but he apparently recognized the difficulties of a more general solution.

M. M. Morris

*92 Barker Ave.*
*Eatontown, New Jersey*

[1] Moon and Spencer, "The dimensions of physical concepts," *Am. J. Physics* **17**, 171–177 (1949).
[2] Starling, *Electricity and Magnetism* (Longmans Green and Co., 1927), p. 383.
[3] E. Buckingham, "On physically similar systems; illustrations of the use of dimensional equations," *Physical Rev.* Ser. 2, **4**, 345–376 (1914).
[4] M. D. Hersey, "A relation connecting the derivatives of physical quantities," *J. Wash. Acad. Sci.* **6**, 620–629 (1916); reprinted *Sci. Papers Nat. Bur. Stand.* **15**, 21–29 (1918).

## Reply to M. M. Morris

In dimension theory, the idea of using several fundamental lengths instead of one is not new, as was pointed out on p. 173 of our paper. The earliest suggestion of this kind seems to have been made by Williams in 1892 (footnote 7 of our paper). Previous attempts, however, have been unsatisfactory because they have not been completely worked out. Our use of $l_r$ and $l_t$ seems to be thoroughly consistent for the whole of physics, and it offers definite advantages over the usual single space dimension. A more complete discussion will appear in our forthcoming dimensions paper in the *Journal of the Franklin Institute*.

To insist that angle is dimensionless is to misunderstand a basic principle of dimension theory, regardless of what Buckingham may have said. Of frequent occurrence are expressions such as $e^x$, where $x$ is in meters. This seems to violate Buckingham's principle, quoted in the preceding letter; but everyone knows that $e^x$ is merely a special case of $e^{\alpha x}$. Here $\alpha$ has the dimensions $1/l$ and is omitted when it happens to have unit numerical value. Similarly, cos $\theta$ is a simplified form of cos $(\alpha\theta)$. The former has become familiar because ordinarily $\alpha$ has a numerical value of unity. Dimensionally, however, the angle $\theta$ cannot be made dimensionless without risk of ambiguity. It has dimensions $l_t/l_r$, and $\alpha$ must then be given the dimensions $l_r/l_t$ in order that the argument $(\alpha\theta)$ shall be dimensionless.

It is not generally realized how much latitude there is in the choice of dimensions. Many consistent dimensional systems can be formulated, and the one to be employed is the one that is most useful. In our work, we have chosen to consider energy as one concept, irrespective of whether it is mechanical energy, electrical energy, thermal energy, or radiational energy. Mr. Morris is shocked at this proposal. He prefers to consider kinetic energy and potential energy as separate and distinct concepts having different dimensions. This is a legitimate attitude, though it would probably result in a dimensional system that is more complicated than ours and is less in accord with the views of most physicists.

As another example of our pragmatic approach, let us repeat the basic idea of the paper: it is more useful to regard dimensions as an attribute of the *concept* than as an attribute of the *unit*. One should speak of the dimensions of energy or force or current, not of the dimensions of the Joule or the Newton or the Ampere.

Parry Moon
Domina Eberle Spencer

*Massachusetts Institute of Technology*
*Cambridge, Massachusetts;*
*Brown University*
*Providence, Rhode Island*

## Eliminating the Physics Final Examination

LAST November the faculty of George Pepperdine College decided to eliminate final examinations during the remainder of the school year. This temporary arrangement was greeted with enthusiasm by the faculty and the students alike. The faculty was relieved because each member formerly had to grade at least five sets of final examinations each term and then rush to get the grades in on time. Each student was happier because he formerly felt he had staked all on the final examination. To him, his question: "What did I get on the final?" was practically the same as the question: "What was my term grade?"

Some may feel that a physics teacher would not have enough opportunity to test over the entire subject-matter of the term, were his finals eliminated. But any amount of overlapping, selected or general, may be made in successive tests. Physics, moreover, is a cumulative subject.

With the final examinations eliminated we, of course, tested more frequently, and in order to hold students in class to the last day, absentees on this day were penalized somewhat. I personally feel that an absence is a fact which should not generally carry a penalty. I believe a teacher, in specifying a grade, should do so on the basis of accomplishment rather than an adherence to an arbitrary set of rules. After all, absence fosters its own inevitable result in an ignorance of the subject, and this ignorance ordinarily is revealed in examinations. With the final examinations eliminated, however, there does seem to be some justification for penalties against absences during the last days.

My own method of dealing with such absences, as well as inattention, etc., was customarily to give a 15-minute test at the end of the last meeting of each class. The interest in the subject was thus kept alive to the end. The use of the last week for regular class work was especially welcome to me, as the class covered almost another chapter during this time.

I see no reason why the arrangement should not work just as well in institutions using the semester system. George Pepperdine College is changing to the semester system this fall and it is my hope that the finals will be permanently eliminated.

EARL C. REX

*George Pepperdine College*
*Los Angeles, California*

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# ANNOUNCEMENTS AND NEWS

## Book Reviews

**Quantum Mechanics.** LEONARD I. SCHIFF. Pp. 404+xii, Figs. 30, 23×15 cm. McGraw-Hill Book Company, Inc., New York, 1949. Price $5.50.

The teaching of quantum mechanics is a difficult task. The student beginning this subject presents the instructor with a varying background in physics and a wide range of fields to which the knowledge gained will finally be applied.

The formal course in quantum mechanics should not be offered for beginners. A previous course in modern physics should have integrated his knowledge of classical mechanics, thermodynamics, and electromagnetic theory. The difficulties of classical theory with specific heats, the dual aspects of light and matter, the experiments of Franck and Hertz, and of Stern and Gerlach should have been thoroughly discussed. Along with these failures there should be made clear the success which classical theory has had in explaining many phenomena, e.g., the simple Zeeman effect. Only then can the student be given a proper motivation for the new developments. As an introduction the instructor could, of course, merely record a system of postulates for quantum mechanics, then proceed to the mathematical machinery and finally claim justification of the theory by its success in verification of experimental results. But this postulate-theorem presentation will hardly convince the student. The instructor must try to make the broad principles, e.g., the correspondence principle or the uncertainty principle, plausible by extensive examples. At the same time, he must beware of creating new dogma, for it must not be assumed that the theory of the structure of matter is in any final form. His main goal must be fostering of independent thought.

The introductory chapter of Professor Schiff's textbook presents only a very brief discussion of the new concepts. Adequate background material for the student would have to be obtained from the references.

Too many courses (and textbooks) in quantum mechanics go astray with discussions of properties of differential equations and special functions. The instructor must assume that, right at the start of graduate work, the introductory course in theoretical physics gives the student this mathematical background. This provision eliminates the exhausting repetition of mathematical material in the various graduate courses. Professor Schiff has handled mathematical detail very well. The analytic solutions (hydrogen atom, harmonic oscillator, etc.) have been restrained to a sensible proportion of the book. This condensation has permitted the inclusion of excellent sections on collision problems, the treatment of which has been woefully neglected in previous texts. The last sections of the book introduce the student to relativistic quantum mechanics and quantized fields.

It is difficult to propound problems in quantum mechanics for the student which are not mere mathematical exercises. The solution of textbook writers in the past has been to omit problem material or keep it on the kindergarten level. The exercises in the present text are useful

applications of the general methods to representative physical problems and form a real test of the student's grasp of the material.

Schiff's *Quantum Mechanics* represents so great an advance over its predecessors (in English) in this field that any minor flaws in detail or presentation must be discounted.

MORTON HAMERMESH
*Argonne National Laboratory*

**Introduction to Atomic Physics.** OTTO OLDENBERG. Pp. 373 +xiii. McGraw-Hill Book Company, Inc., New York, 1949. Price $5.00.

This book, very justifiably dedicated to James Franck, is a descriptive survey of Atomic Physics. It is a very excellent survey, characterized by exceptional judgment in the allocation of space and emphasis given to the various topics, and by exceedingly well worded discussions. A very great number of experimental phenomena and principles are briefly, simply, and correctly expounded. In this respect, *Introduction to Atomic Physics* reminds one of Hull, *An Elementary Survey of Modern Physics*,[1] and similarly it should serve as an excellent up-to-date reference on the nature of atomic phenomena. It is obvious that the teacher who uses this book as a text must possess knowledge far beyond the elementary explanations given if he is to satisfy keen and inquisitive students regarding the phenomena discussed. Without inspired treatment a memory course will result.

As stated in the preface, the text results from a course given by the author at Harvard for students who have completed a one-year introductory course in physics. It is nonmathematical and places emphasis on "understanding as opposed to accepting on authority." The reviewer is one of those old-fashioned persons who believes that children should eat a reasonably good meal before partaking of dessert. This book is distinctly dessert. It could easily cause intellectual indigestion if not preceded by a properly balanced diet. We doubt that a "one-year introductory physics course and familiarity with the elements of chemistry" is sufficient to permit digestion to the point of "understanding." We believe the book should be served in the nature of a survey of atomic physics as a dessert for major students completing their undergraduate courses in physics.

As indicated by the detailed Table of Contents, the presentation is exceptionally well organized, though it is possible that the unequal length and importance of chapters may make regular assignments difficult. The seven parts into which the book is divided are generally preceded by brief statements of purpose. The titles of these parts indicate clearly the fields covered: I. Structure of Matter as Revealed in Chemistry, II. Gases, III. Structure of Electricity, IV. Structure of Light, V. Electronic Structure of Atoms, VI. Nuclear Structure, VII. Wave Nature of Matter. There are from two to six chapters for each part. In all there are 26 chapters in addition to a "Survey of History and Methods." Each chapter or part is concluded with a brief summary. Problems, with answers at the end of the book, are given on most chapters. These problems are unusually thought-provoking and with the hints given should be considered part of the text. In one of the several appendices a list of demonstrations and laboratory experiments which might accompany the course are given. Tables of units and atomic constants are also given. The index is satisfactory. One could wish that the author had given references to original material throughout. This omission is alleviated by the mention of names and dates in the body of the text. The text is unusually free of errors. The spelling of the name of element 43, Technetium, differs from that suggested by the discoverers of the element.[2]

We thoroughly recommend *Introduction to Atomic Physics* as a careful survey and as an excellent reference text.

FRANCIS G. SLACK
*Vanderbilt University*

[1] The Macmillan Company, 1936.
[2] *Nature*, **159**, 24 (1947).

**Modern Introductory Physics.** IRA M. FREEMAN. Pp. 481, Figs. 264, 23×15 cm. McGraw-Hill Book Company, Inc., New York, 1949. Price $4.50.

The title of this book is aptly chosen. It is an introductory physics textbook that is modern in at least two ways: a large percentage (about 30 percent) of the contents is devoted to "modern physics," and it is written in an attempt to achieve the objectives of a general education curriculum.

Dr. Freeman's book is one of the first to break completely away from the traditional style of the last quarter century. The author states in the preface that he is writing the book for "courses aimed primarily at giving the student a comprehensive idea of the development and method of" physics. He also believes in treating a sharply limited number of topics thoroughly, and in choosing these topics to "answer some of the questions arising in the average person's mind regarding the more recent developments in physics" in a satisfying manner. The result of this approach is refreshing.

A comparison with several widely used elementary textbook shows that although there are half the usual numbers of chapters and sections, the number of pages in only one-third less. Many topics are discussed more thoroughly than in most books for nontechnical students. A few topics are treated more adequately than in most books for technical students. In general, discussions of mechanics, sound, and electricity are each one-half their usual page length. Light is treated in the usual page length but emphasis is shifted, particularly in the direction of spectroscopy. Contemporary physics occupies about five times the number of pages usually devoted to it.

While most physics professors would agree with the necessity for limiting the scope of a textbook, not all would agree completely with the author's choice of topics to be excluded. Among the familiar topics missing, or nearly so, are: mechanics of fluids, elasticity, thermal expansion, heat transfer, alternating currents, and architectural acoustics. In the opinion of the reviewer the author does not always discuss adequately some of the older topics. He writes, for example, about something so basic as torque only that it is a "twist," and few students will understand his discussion of the triode as an amplifier. On the other

hand, there are to be found discussions of such subjects as: band spectra, change of mass with speed, television, Laue spot diffraction, quantum theory, Rutherford's scattering experiment, the Compton effect, and de Broglie's wave theory. Perhaps Dr. Freeman has gone a little too far in the right direction. An old-line major topic like heat ought to make room for contemporary physics, but it should not be almost replaced thereby. Modern physics needs to be limited, also.

In so novel a book some physics teachers might hope to find a single, complete discussion of wave theory, followed by specific treatment of the basic phenomena of sound and light. In this book there is a chapter on "Waves" which is, however, not a complete discussion of wave motion but is largely a chapter on sound waves. Other wave aspects are discussed in later chapters on light. The underlying unity of the two branches of physics thus remains concealed.

It is commendable that there is no traditional chapter on permanent magnetism. Instead, permanent magnetism is properly discussed in a chapter on electromagnetism which appears after one on electric currents. Magnetic poles are not described as physical entities—the pole concept playing a subordinate role in the development of magnetic theory. Treatments of conservation of momentum and electrostatic potential are given in a fundamental way even though the textbook is intended to be used by students who are not prospective scientists or engineers. The author flirts with calculus notation often, using delta-notation and writing about the limiting values of ratios. Only absolute units are used in problems on dynamics. Formulas are de-emphasized—the student being encouraged to use physical reasoning and fundamentals in problem solving.

The author gives "more attention than is usual at this level to the historical and philosophical aspects of the science." This is well done throughout the text. However, it is questionable whether an initial chapter on "The Method of Science" might prove dull and meaningless at this point. A similar chapter at the end of the book, or the same material dispersed through it, seems the better order.

For a first edition the textbook is remarkably free from errors and misleading statements. However, the reviewer feels that an avoidable confusion between mass and weight is unintentionally created. Density is defined as the ratio of *mass* to volume but it is often used as the ratio of *weight* to volume; the kilogram is listed only as a *mass* unit but the student has a problem of computing his *weight* in kilograms; the *center of gravity* of the universe is mentioned; atomic weights rather than atomic masses are used.

The format of the book is attractive. Most illustrations are line drawings and, with few exceptions, display good proportions and a pleasing balance of line and letter. The style of writing is clear and decisive. At the end of most chapters are summaries, lists of reference books and films, and good exercises.

There are directions for seven experiments intended for some of the sessions of a weekly two-hour laboratory. The author suggests that other sessions may be used for problem drill, showing of films, etc. The traditional type of laboratory is well known to be unsuitable for this kind of course; the author's method of regarding films and numerical problems as bona fide laboratory materials has much to commend it.

Dr. Freeman's book points the way in which many of our elementary physics courses and textbooks must change. Physics teachers have been trying to teach so much material that it has not been taught well. The scope of physics increases rapidly, yet the students' powers of assimilation and background knowledge do not expand. Hence, the elementary course must present a limited number of topics in a better way. Furthermore, topics must be chosen to more nearly provide that knowledge of physics which is needed by everyone in the modern world. These are two of the problems of physics teachers and Dr. Freeman has made progress toward solving them. It is not an easy task.

J. W. McGrath
*Kent State University*

**Physics, Principles and Applications.** Henry Margenau, William W. Watson, and Carol G. Montgomery. Pp. 760+x, 6×9 in. McGraw-Hill Book Company, Inc., New York, 1949. Price $5.00.

This book has grown out of a sophomore course in general physics at Yale University, a course for engineering students and mathematics and physical science majors. In the opinion of this reviewer, it is one of the outstanding texts of its type. The emphasis throughout is on basic principles, the viewpoint is modern, and the general level of sophistication and rigor seems to be excellently balanced between the conflicting demands of teachability, on the one hand, and professional competence, on the other. The book is designed for the student who has had a course in calculus, or who is taking such a course simultaneously. The first four chapters, including statics and elasticity, contain no calculus, but, with kinematics in Chapter V, fundamental notions of differential and integral calculus are introduced, and they are employed with increasing frequency thereafter.

The length of the book is really considerable, being greater, because of its conciseness, than its physical size would suggest. Approximately three-eighths of the sections are starred, and may be omitted without affecting the continuity of the remainder. The authors state that the unstarred material may be covered adequately in a class meeting three hours a week for two terms. At that rate, coverage of the entire book would require a little more than three terms. Since many interesting and important matters are left to the starred sections, the predicament of the present-day introductory professional course is clearly illustrated. The ideal solution probably is to extend the course to two years, as a few schools have already done, but this usually demands a beginning in the freshman year and a mathematical background in entering students which cannot be expected in most institutions. If the course is to be limited to one year and a desirable level of rigor and logical completeness is to be maintained, it seems that many items of esteemed tradition must be tossed bodily

overboard. There is considerable danger that a book of the present type will be badly mishandled by the doting instructor who cannot resist assigning every alluring, fact-crammed paragraph.

The major part of the book is devoted to classical mechanics, electromagnetism, heat, sound, and light, but there is a reasonable amount of "modern physics," besides. The last two chapters are devoted to atomic and nuclear structure, respectively, and a good deal of material of this nature has been nicely worked into the body of the text. Thus, for example, the chapter on planetary motion is supplemented by a brief account of the Bohr quantum conditions; the phenomenological account of specific heats is accompanied by a discussion of their kinetic theory basis and also the principal quantum mechanical effects in this connection; and the sections on electricity and magnetism are enlivened with such items as the nuclear atom, the Millikan oil drop experiment, the mass spectrograph, and the betatron.

A noteworthy feature is the treatment of magnetism, in which moving charges are regarded as the fundamental source of magnetic fields, and magnetic poles enter as derived concepts. The reviewer agrees that in a text of this type such a viewpoint is decidedly preferable, inasmuch as modern professional practice has definitely swung in this direction, and efforts to demonstrate the existence of isolated magnetic poles have not yet been widely accepted. It is surprising, however, to find that the very useful Ampere circuital law has been omitted, and the purist will be offended by the many places in which "current flows."

There is a minor amount of historical matter sprinkled through the book, and likewise, there are occasional philosophical digressions. The latter are uniformly excellent, and one wishes that there could have been many more. The mode of presentation of new ideas is deductive in virtually every case, no time being spent in describing experimental facts first and indicating the processes of induction which led to the concepts and laws. There is a consequent gain in compactness, and probably a loss in easy understandability, which may be defensible in view of the type of course for which the book is designed.

Both the dust-jacket blurb and the publisher's advertisements claim that the book contains "proof of the mass-energy relation," a regrettable statement, since no more than the relativistic work-energy theorem is actually given, the connection with momentum conservation, by way of the Lorentz transformation, necessary for identifying the rest energy, being given no mention. Even minor flaws seem to be rare in this book, however, and it is clearly an important and needed addition to the rather small group of upper level general texts.

George H. Vineyard
*University of Missouri*

## Presentation of the 1948 Oersted Medal for Notable Contributions to the Teaching of Physics

On April 23, 1949 a group from the Office of the Naval Attaché of the American Embassy in London presented to Professor Arnold Sommerfeld the Oersted Medal and Certificate awarded to him at the Eighteenth

Fig. 1. Professor Sommerfeld accepting the award. From left to right: Mr. E. G. Touceda, Lt. Cdr. L. R. Dailey, Professor Sommerfeld, Professor G. J. Comstock, and Cdr. R. H. Lambert.

Annual Meeting in New York, January 27–29, 1949. The presentation took place in Munich, Germany, where Professor Sommerfeld has long served as Professor of Physics in the University. Professor Gregory Comstock made the presentation, assisted by Cdr. R. H. Lambert, Lt. Cdr. L. R. Dailey, Mr. E. G. Touceda, and Dr. B. D. Cullity. The Office of Naval Research has provided a photograph (Fig. 1) showing Professor Sommerfeld receiving the medal.

## New Members of the Association

The following persons have been made members or junior members (J) of the American Association of Physics Teachers since the publication of the preceding list [*Am. J. Physics* **17**, 395 (1949)].

**Abernethy,** Joseph J., 2519 Nagle St., Houston 4, Tex.
**Abrams,** John Werner, 525 Mission St., San Francisco 5, Calif.
**Anthony,** B. B., Manhattan College, Bronx 63, New York, N. Y.
**Bacon,** Kenneth H. (J), 1415 S. Quincy, Apt. 4, Tulsa, Okla.
**Belavic,** Andrew Michael, 1007 East 71 St., Cleveland 3, Ohio.
**Bell,** Clinton W., Jr. (J), 381 Vine St., Milton, Pa.
**Berendt,** Raymond D. (J), 35 Rittenhouse St., Simpson, Pa.
**Beshers,** Daniel Newson (J), Physics Department, Swarthmore College, Swarthmore, Pa.

(*continued on page 458*)

## Archie Garfield Worthing, 1881–1949

Dr. A. G. Worthing died at Pittsburgh, Pennsylvania, on July 30, 1949, four days after an abdominal operation. He is survived by his wife, Exie Worthing, his daughters, Marion and Helen, and a son, Robert.

Dr. Worthing was born on an Iowa farm. He received bachelor degrees from the Oshkosh Normal School and from the University of Wisconsin. While doing graduate work at Wisconsin, he served as computer for the observatory. From the University of Michigan, he received the doctorate. Dr. Worthing taught two years at the University of Iowa and then for fifteen years did research work at the Nela Park Laboratory. During this period, he became well known for his studies on the properties of tungsten at high temperatures and was co-author of a booklet so well-known in the illuminating industry that it is sometimes called "The tungsten bible."

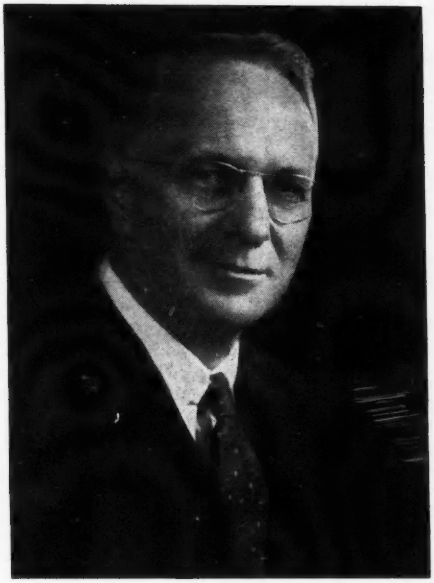
Twenty-four years ago, Dr. Worthing came to the University of Pittsburgh to serve as head of the physics department. Frequent staff meetings were held and every matter of executive importance—apart from our own salaries—was fully discussed. With one or two exceptions, we always arrived at unanimous agreement. After ample discussion, every question was decided by vote. This procedure had two advantages: First, complete discussion favored wise decisions; second, it fostered high morale—we felt that this was our department.

During nearly a quarter of a century at Pittsburgh, Dr. Worthing devoted a great deal of time to work on committees of the national societies. Nomenclature and definitions particularly interested him. He served on the Governing Board of the American Institute of Physics and the Executive Committee of the Sigma Pi Sigma Honorary Physics Society. He was elected vice-president and then president of both the American Association of Physics Teachers and the American Optical Society.

What were Archie Worthing's outstanding traits? All of his friends whom I have consulted have emphasized his thoroughness and accuracy. Our former colleague, Dr. Arthur Ruark, now at Johns Hopkins University, states: "He was a champion of intellectual rectitude. A passion for accuracy was the keynote of all his thoughts, words, and deeds. The Angel of Ultimate Truth stood ever at his elbow."

Another former colleague, Dr. T. H. Osgood of Michigan State College, writes: "From him I learned the true importance of accuracy of statement and of impartial consideration of all data that bear upon a problem. Meticulous attention to detail and a compelling sense of responsibility were characteristic of the man."

Dr. Worthing had abundant scientific curiosity. His interest extended to all branches of physics. Searching questions at colloquia, doctoral examinations, and national meetings helped to clarify many issues. He was slow to make a decision but very sure-minded. At luncheon one day, a physicist-friend was discussing a question in his own field. Dr. Worthing disagreed with him as to a certain point. Said the friend, "I know, Archie, that it will turn out that you are right, but here is how I look at the matter." Sure enough, further discussion proved that Worthing was right. He was sure-minded in many fields.



A. G. Worthing

Dr. Worthing taught physics zealously. He emphasized fundamentals. Optimistically, he believed that any student —given time and effort—could conquer general physics. So firm was this conviction, that often Worthing's section would get far behind the rest of us. He was so anxious to make certain that every student realized the difference between mass and weight, that time had no meaning. This same thoroughness characterized his intermediate and graduate school teaching. He was proud of his new type of *basic physics course*, in which he emphasized with meticulous detail the fundamentals of physics and aimed to correct sloppiness of expression and thought.

As by-products of his teaching, Worthing co-authored the pioneer "Outlines of atomic physics," as well as a textbook on heat, and one on precision in measurements.

To me, Archie Worthing's outstanding trait was his tolerant kindliness. For twenty-four years we worked together. During all those years, I never heard him speak harshly of anyone. He was quick to see good in his fellow men and slow to condemn.

He was a champion of intellectual rectitude, a zealot for precision, a careful scholar, an excellent teacher, and a true friend.

O. H. Blackwood

(*continued from page 456*)

**Blakeslee,** Donald Jack (J), 1005 Washington Ave., Kalamazoo 23, Mich.
**Boden,** Evan H. (J), Bucknell Village, Apt. 18, Lewisburg, Pa.
**Browning,** John Marvin, Jr. (J), Box 6797, Louisiana State University, Baton Rouge, La.
**Burkhard,** Eldred L. (J), Wesleyan Trailer Camp, Lincoln, Nebr.
**Caillet,** Cyril A., Jr. (J), Hahnville, La.
**Cameron,** Gerald Thomas (J), 1 Conrad St., Dorchester, Mass.
**Carlson,** Arthur F., Qtrs. 21N, Michigan College of Mining and Technology, Sault Ste. Marie, Mich.
**Carter,** Mrs. Anne F., 1910 Regent St., Madison 5, Wisc.
**Choate,** John Sargent (J), R.F.D. 3, Waterville, Me.
**Clary,** Harry Earl (J), 1514 Vale Rd., Apt. 281, Akron 6, Ohio.
**Cochran,** Lewis Wellington, Physics Department, University of Kentucky, Lexington, Ky.
**Cook,** Roy H., S. Dakota School of Mines and Technology, Rapid City, S. Dak.
**Couch,** Laurence J. (J), P.O. Box 354, La Porte, Ind.
**Crawford,** Harold F. (J), Keene Valley, N. Y.
**Croze,** Martin Wilbert, 212 Walnut St., S.E., Minneapolis 14, Minn.
**Cruser,** Melvin E., Jr., Box 86, Crozet, Va.
**Davis,** William Howard, Physics Department, University of Buffalo, Buffalo 14, N. Y.
**Deall,** Louis (J), 6805 Washington Ave., St. Louis 5, Mo.
**Degnan,** W. G. (J), 116 Babcock St., Hartford 6, Conn.
**Edgett,** Curtis Clinton, 45 Rochester St., Lima, N. Y.
**Erwin,** John Winton (J), 202 Shelden St., Houghton, Mich.
**Foster,** Donald C. (J), 103 S. 8th Ave., Bozeman, Mont.
**Fouts,** S. Russel, Rte. 1, Lombard, Ill.
**Galloway,** Howard L., Jr. (J), 1323 Poplar Ave., Halethorpe 27, Md.
**Germain,** Lawrence Seymour, Physics Department, University of California, Berkeley, Calif.
**Gminder,** Russell (J), 527 W. Henderson St., Salisbury, N. C.
**Gorson,** Robert Owen (J), 4304 Walnut St., Philadelphia 4, Pa.
**Hatlem,** Edward G. (J), Taylor, Wisc.
**Hilton,** Alfred Brooks (J), Box 3346, Virginia Tech. Station, Blacksburg, Va.
**Hipsher,** Warren L., Jr. (J), 1644½ E. Admiral Blvd., Tulsa, Okla.
**Holcomb,** Donald Frank (J), 866 Lorena Ave., Wood River, Ill.
**Holeman,** Oliver Blake, 1400 Bishop St., Little Rock, Ark.
**Hollenberg,** Lee (J), 552 Cajon St., Redlands, Calif.
**Holloway,** Kenneth Orville (J), 450 S. Capitol St., Salem, Ore.
**Honora,** Sister Mary, R.S.M., Edgecliff, Walnut Hills, Cincinnati, Ohio.
**Hoyer,** Wilmer A. (J), 2804 Wooldridge Dr., Austin, Tex.
**Hudson,** Richard DeLano, Jr., 102 Highland Ave., Montclair, N. J.
**Hurd,** Yorick Gordon, 164 Brooks St., W. Medford 55, Mass.
**Jones,** Richard Nelms (J), 450 Prince Ave., Athens, Ga.
**Kaiser,** Henry R. (J), Apt. B10–1 Adair Village, Ore.
**Kelly,** Lewis, Jr. (J), 2354 Myrtle Ave., Baton Rouge, La.
**Kenny,** Patrick Joseph (J), 3442 28th St., Long Island City 6, N. Y.
**Ketchum,** Donald James (J), 1115½ Hope St., S. Pasadena, Calif.
**Lake,** Robert E., Pratt Institute, Brooklyn 5, N. Y.
**Lapetina,** Joseph M., Albany College of Pharmacy, Union University, Albany, N. Y.
**Lapointe,** Alfred E. (J), 622 N. Bernadotte St., New Orleans, La.
**Latimer,** Paul (J), 39 Princeton Way, Atlanta 6, Ga.
**Lauroesch,** Thomas J. (J), 643 Orchard Parkway, Niagara Falls, N. Y.
**Leffingwell,** George Edwin, State Teachers College, Millersville, Pa.
**Levine,** Joseph, 1583 Northland St., Lakewood, Ohio.
**Long,** Howard Charles, 364 Burton Ave., Washington, Pa.
**Lundquist,** Charles A. (J), P.O. Box 96, Webster, S. D.
**Macres,** George S., 1321 S. Troy St., Chicago 23, Ill.
**Maznicki,** George Walter (J), 20 Shultas Place, Hartford, Conn.
**McCausland,** Doris E., 47 Beaumont St., Dorchester 24, Mass.
**McClean,** Donald E. (J), 1139 West 89th St., Los Angeles 44, Calif.
**McClure,** Joel William, Jr. (J), Apt. 303, 728 Clark St., Evanston, Ill.
**McCoy,** Curtis Logan, Jr. (J), 2820 20th St. West, Birmingham 8, Ala.
**McLaughlin,** William Lowndes (J), 130 Overton Place, Keyser, W. Va.
**Melzer,** William Robert (J), 1566 Roycroft Ave., Lakewood 7, Ohio.
**Moore,** William T., Jr. (J), 755 Locust St., Lebanon, Pa.
**Morgan,** Dorsey Lee, Southern University, P.O. Box 9574, Baton Rouge, La.
**Muschlitz,** Earle Eugene, 251 S. Atherton St., State College, Pa.
**Need,** John Logan (J), 119 Kendall Rd., Walnut Creek Calif.
**Nelson,** John William (J), 6144 Sherry Ave., St. Louis 20, Mo.
**Oberheim,** Walter A. (J), 2682 N. Burling St., Chicago 14, Ill.
**Oliver,** Howard William (J), 1237 S. Citrus Ave., Los Angeles 35, Calif.
**O'Neill,** Edward Leo (J), 39 Summer St., West Roxbury 32, Mass.
**Oselka,** Milan Charles (J), 2314 Cuyler Ave., Berwyn, Ill.
**Pappas,** Peter, Jr. (J), 3035 Britton St., Dallas 16, Tex.
**Patrie,** Lawrence A., Rte. 1, Fredonia, N. Y.
**Patterson,** James Reid, Physics Department, North Carolina State College, Raleigh, N. C.
**Porter,** Carleton Eugene (J), 43 Crescent St., Lowell, Mass.
**Prucha,** Rudolph William, 135 N. Prairie St., Whitewater, Wisc.

**Ratcliffe,** Jack J. (J), 3916 E. 1st St., Tulsa 5, Okla.
**Rau,** Richard R. (J), 307 Bewley Rd., Havertown, Pa.
**Remmler,** Olaf Donald (J), P.O. Box 55, Farmingdale, L. I., N. Y.
**Rexroad,** Harvey Nixon, 686 Grand St., Morgantown, W. Va.
**Roe,** Bill F. (J), 813 St. Louis Ave., Excelsior Springs, Mo.
**Russell,** Budd Roswell, Randal Morgan Laboratory, University of Pennsylvania, Philadelphia 4, Pa.
**Saling,** James H. (J), Apt. 18, Muhlenberg College, Allentown, Pa.
**Scheibner,** Edwin J. (J), 1084 Austin Ave. N.E., Atlanta, Ga.
**Schultz,** Merle A. (J), 44 Walton Ave., Ardmore, Pa.
**Sellheim,** Henry Dale (J), 2700 University Ave., Grand Forks, N. Dak.
**Senkovits,** Ethel Jean (J), 638 River Drive, Garfield, N. J.
**Shewan,** William (J), Rte. 5, Valparaiso, Ind.
**Silver,** Reuben, 569 Linden Blvd., Brooklyn 3, N. Y.
**Smith,** Preston Wood, 38 Main St., Potsdam, N. Y.
**Smith,** Russell Paul, Grove City College, Grove City, Pa.
**Soderstrum,** John Clark (J), 1281 Mills St., Menlo Park, Calif.
**Soule,** David E. (J), Longden Hall, DePauw University, Greencastle, Ind.
**Spatz,** Wilber D. B., Department of Physics, Lehigh University, Bethlehem, Pa.
**Stewart,** John Westcott (J), 200 Mercer St., Princeton, N. J.
**Stone,** Clinton A. (J), 13 A. St., MSC, Bozeman, Mont.
**Stone,** Robert E. (J), 5263 E. 1st St., Long Beach 3, Calif.
**Sutcliffe,** Charles Herbert (J), 94 Division St., Salamanca, N. Y.
**Swanson,** Howard Paul (J), 827 Kellogg Ave., Ames, Ia.
**Taslitt,** Norman (J), 34 Russell St., Hartford, Conn.
**Thom,** Arthur R. (J), 1182 N. 10th St., Corvallis, Ore.
**Tonik,** Albert B. (J), 2928 W. Oxford St., Philadelphia 21, Pa.
**Trumbull,** David E. (J), 16 Eddy St., West Newton, Mass.
**Vigue,** Kenneth James (J), Apt. 6B, Colby College, Waterville, Me.
**Vineyard,** George Hoagland, Department of Physics, University of Missouri, Columbia, Mo.
**Watkins,** Margaret (J), 2919 Scarborough Rd., Cleveland Heights 18, Ohio.
**Webb,** Francis Henry, Jr. (J), 3454 Vosberg St., Pasadena 8, Calif.
**Wells,** Thomas Earl, Campus Club, University of Idaho, Moscow, Idaho.
**Wilson,** Jo A. (J), 94 N. Congress St., Athens, Ohio.
**Wingate,** Catharine Louise, 188 Commonwealth Ave., Chestnut Hill, Mass.
**Worden,** Mary Ellen (J), 1900 Oak Dr., College Park, Md.
**Wullert,** John R. (J), 624 E. Locust St., Scranton 5, Pa.

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# RECENT MEETINGS

## Indiana Section

The regular spring meeting of the Indiana Section of the American Association of Physics Teachers was held at Hanover College, Hanover, Indiana, on May 14, 1949. Thirty-eight members and guests were in attendance. Earl Martin, President of the Section, presided during the presentation of the following papers.

**Wave motion demonstration.** Seth E. Elliott, *Butler University.*

**Demonstrations in the study of light.** Ralph Loring, *University of Louisville.*

**The neglect of molar quantities in physics courses.** J. C. Hendricks, *Franklin College.*

**Laboratory work in general education (physics and chemistry).** James F. Mackell, *Indiana State Teachers College.*

**Impedance problems.** A. D. Hummel, *Ball State Teachers College.*

**The off-center magnetic field for a circular current.** Orrin H. Smith, *DePauw University.*

Dinner was served at the Clifty Hotel, Clifty Falls State Park. At the business meeting, Mr. R. W. Lefler gave an extended report on his visit to the National Meeting in New York City. Professor A. R. Thomas of Valparaiso was chosen as the new president. Mr. Earl Martin was elected secretary to succeed Dr. Mason E. Hufford.

Valparaiso University was designated as the place for the next meeting.

Earl Martin, *Secretary*

## Chicago Section

The Chicago Section of the American Association of Physics Teachers met at the Navy Pier Branch, Chicago, Illinois, of the University of Illinois on May 21, 1949. Dr. R. E. Harris of the University of Illinois was the host. Dr. H. R. Vorhees of the University of Chicago served as chairman for the meeting. Following a luncheon papers were presented and a discussion session held.

1. **Research in biophysics.** Ray S. Snider, *Northwestern University*.
2. **Normal and oblique precessions; the effects of centripetal force and variable torque.** Philip A. Constantinides, *Wilson Branch, Chicago City Colleges.*
3. **Demonstration of new equipment.** R. E. Harris, *Navy Pier Branch, University of Illinois.*
4. **Discussion on current topics.**

Philip A. Constantinides, *Secretary*

## Kentucky Section

The annual spring meeting of the Kentucky Section of the American Association of Physics Teachers was held on April 22, 1949, at the Physics Building of the University of Louisville. This meeting was held in conjunction with the annual meeting of the Kentucky Education Association. Dr. R. A. Loring, *University of Louisville*, presided. Forty-

six members and guests were present. The program consisted of the following contributed papers:

1. **A study of the radiometer.** Jess B. Huff, Jr. and C. B. Crawley, *University of Kentucky.*—The direction and amount of rotation of a radiometer as a function of pressure, time, and light intensity were determined for the case of silver vane illuminated, black vane illuminated, and both vanes illuminated. The initial deflection of the silver vane was in the direction of the source. The final deflection, for each case, was in the direction of radiation pressure. The point of maximum sensitivity of the radiometer was found to be at about 0.012 mm Hg.

2. **The pressure coefficient of air in the general laboratory.** F. M. Carter and O. T. Koppius, *University of Kentucky.*—Apparatus was designed for determining the pressure coefficient of air in the general laboratory. A 500-cc glass reservoir was connected by a capillary tube to a manometer. Thermometers in the reservoir and surrounding water bath indicated gas temperature and equilibrium. A drying agent, $CaCl_2$ or $P_2O_5$, was sealed in the reservoir. The coefficient was determined from a pressure *vs.* temperature curve by the relationship slope/pressure at 0°C. Ninety student determinations gave an average of 0.00371/°C with a range of 0.00360/°C to 0.00380/°C.

3. **The Navy Reserve Unit in Electronics associated with Centre College.** Roy Ellis, *Centre College.*

4. **Some experiments in hygrometry.** D. E. Eastwood and K. O. Lange, *University of Kentucky.*—An electric hygrometer of the Dunnmore type was subjected to various humidities at pressures in the range of one to four atmospheres. A marked effect on the calibration of the hygrometer was found, such that, at higher pressures a positive correction factor must be applied to the indication.

5. **Scintillation counting.** W. L. Lawrence and L. W. Cochran, *University of Kentucky.*

6. **Student spectrometer from surplus materials.** R. A. Loring and R. L. Remely, *University of Louisville.*

At the business meeting, the following officers were elected for 1949: *President,* R. A. Loring, *University of Kentucky; Vice-President,* Waldmar Noll, *Berea College; Representative to Executive Committee,* L. A. Pardue, *University of Kentucky; Secretary-Treasurer,* L. W. Cochran, *University of Kentucky.*

L. W. Cochran, *Secretary*

## Michigan Teachers of College Physics

The Michigan Teachers of College Physics met at Calvin College and Seminary, Grand Rapids, Michigan on Saturday, May 21, 1949. Morning and afternoon sessions were held in the Seminary Building. Arrangements for the meeting were under the direction of Professor H. J. Wassink, Calvin College. Dr. E. F. Barker and Dr. Thomas H. Osgood presided over the sessions. Eight contributed papers and two supplementary contributions were presented.

1. **Friction.** G. P. Brewington, *Lawrence Institute of Technology.*
2. **Science on television.** E. R. Phelps, *Wayne University.*
3. **Magnetic amplifiers demonstration.** W. E. Sargeant, *General Motors Research and Lawrence Institute of Technology.*
4. **Report on the Washington Meeting.** E. F. Barker, *University of Michigan.*
5. **Thomas Hariot, 1560–1621.** Dr. John Shirley, *Department of English, Michigan State College.*
6. **A proposed intermediate course in spectroscopy.** William Lewis, *University of Detroit.*
7. **The role of the teacher in the general physics course.** W. W. McCormick, *University of Michigan.*
8. **An elementary derivation of the formula for centripetal acceleration.** W. T. Payne, *Michigan State College.*
9. **Supplementary contributions:**
   **Sound pulses.** E. K. Holland-Moritz, *Wayne University.*
   **Demonstration of Euler's angles.** L. Horn, *Wayne University.*

Luncheon was served at the Plymouth Congregational Church. A program for the ladies included a tour of the Baker Furniture Exhibition and the Furniture Museum.

## University of Iowa Colloquium for College Physicists

The 10th annual University of Iowa Colloquium for College Physicists was held on June 16 to 18, 1949. It was attended by 123 registrants from 68 institutions in 21 states. The program follows.

**Demonstration of an analogue computer for differential equations, high speed counter of several thousand per second, super stop watch, a memory tube.** Cyril N. Hoyler, *Radio Corporation of America.*

**Delusion of scientific method.** H. Kruglak, *University of Minnesota.*

**I have been to the village.** D. Q. Posin, *North Dakota State College.*

**Annual exhibit of new devices by members.** C. L. Andrews, *New York State College for Teachers;* William Azbell, *Bradley University;* F. E. Christensen, *University of Minnesota;* S. W. Cram, *Kansas State Teachers College;* C. A. Culver, *Park College;* D. L. Eaton, *Northern Illinois State Teachers College;* Lester T. Earls, *Iowa State College;* John A. Eldridge, *State University of Iowa;* Peter E. Fossum, *Saint Olaf College;* Harold Q. Fuller, *University of Missouri;* Grant O. Gale, *Grinnell College;* John Harty, *New Mexico School of Mines;* Zaboj V. Harvalik, *University of Arkansas;* R. L. Henry, *Carleton College;* W. J. Hooper, *The Principia College;* J. W. Hornbeck, *Kalamazoo College;* H. R. James, *Hastings College;* A. Frances Johnson, *Rockford College;* Paul E. Martin, *Wheaton College;* J. E. McDonald, *Iowa State College;* Roy H. Mortimore, *Graceland College;* H. D. Rix, *Pennsylvania State College;* Paul Rood, *Western Michigan College;* Paul N. Russell, *University of Missouri;* Ancil R. Thomas, *Valparaiso University;* Earl W. Thomson, *U. S. Naval Academy.*

**Special exhibit of microwaves.** C. L. Andrews, *New York State College for Teachers.*

**Surface states in semi-conductors.** Gordon C. Danielson, *Iowa State College.*

**The story of vitamin $B_1$.** R. R. Williams, *Research Corporation.*

**Graduate training of college teachers.** Rogers D. Rusk, *Mount Holyoke College.*

**The training of college teachers; experiences of a university examiner.** Leo Nedelsky, *University of Chicago.*

**Teacher training in the graduate school.** Claude E. Buxton, *Northwestern University.*

**A resume of various applications and forms of the gyroscope in industry and in nature.** Carl A. Frische, *Sperry Gyroscope Company.*

**Research in speech.** John C. Steinberg, *Bell Telephone Laboratories.*

**Round table discussions: Contributions to teaching methods**—J. G. Winans, *University of Wisconsin;* **Basic electrical principles through functional methods**—R. A. Rogers, *Iowa State Teachers College;* **The Jamin interferometer for the juniors in optics laboratory**—Orrin H. Smith, *DePauw University;* **Teaching alternating currents**—J. G. Winans, *University of Wisconsin.*

Other features of the Colloquium included several luncheon and dinner sessions, an evening reception at the home of Professor G. W. Stewart, and an open house in the research laboratories of physics and of the radiation laboratory in the Medical Building.

## Seminar on Modern Physics

During the period June 7–10, 1949, the College Physics Teachers of Illinois had the privilege of attending a Seminar on Modern Physics at the University of Illinois. Each

day's program began with a morning session, in which the theory of the day's subject was presented. In the afternoon, laboratories were visited which pertained to the subject. After the laboratory visitation, a coffee hour was followed by informal discussion with opportunities for questions concerning the experiments observed in the laboratories. The subjects presented during the four days were as follows:

Tuesday, June 7. **Meson Theory and Particle Detection.** Dr. J. W. Snyder, Dr. C. W. Sherwin, and graduate students.
Wednesday, June 8. **Study of Nuclear Energy Levels.** Dr. P. Axel, Dr. W. Meyerhof, and graduate students.
Thursday, June 9. **The Cyclotron.** Dr. A. T. Nordsieck, Dr. G. F. Tape, Dr. P. G. Kruger, and graduate students.
Friday, June 10. **The Betatron.** Dr. D. W. Kerst, staff members, and graduate students.

Thirty-four visiting physics teachers of the state attended the session. They were given cordial welcome and were cared for in excellent fashion. The whole meeting was one of outstanding quality. Dr. Snyder, who was in charge of the local arrangements, stated that the whole Physics staff entered into the preparation of the program with great enthusiasm and they felt that it was a very worthwhile thing to do. Both the local staff and the visiting physicists frequently expressed themselves very favorably toward the total program as planned. The visiting physicists remarked upon the high excellence of the lectures and the laboratory tours.

O. L. Railsback
*Eastern Illinois State College*

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# Proceedings of the American Association of Physics Teachers

## The Troy Meeting, June 23–24, 1949

The American Association of Physics Teachers met jointly with the American Society for Engineering Education at Troy, New York, June 23–24, 1949. C. E. Bennett, G. B. Hoadley, and Duane Roller presided at the various sessions. At the luncheon on Friday, June 24, the two groups enjoyed an address given by Professor John R. Dunning, Columbia University, on "Cooperation Between Physicists and Engineers." The session of contributed papers ended with a showing of the J. Arthur Rank film on "Atomic Energy."

### Invited Papers

*Symposium on the Teaching of Atomic Power Engineering*

A. Typical Present Day Courses:
1. **Science and Engineering of Nuclear Power.** Clark Goodman, *Massachusetts Institute of Technology.*
2. **Oak Ridge Institute of Nuclear Study.** W. G. Pollard, *Oak Ridge Institute of Nuclear Studies.*
3. **Graduate School of Nuclear Engineering.** F. Ellis Johnson, *General Electric Hanford Engineering Works.*
4. **Elementary Courses for Senior Mechanical Engineering Students.** Elmer Hutchisson, *Case Institute of Technology.*

B. Training Needed in Industry:
K. H. Kingdon, *Knolls Atomic Power Laboratory, General Electric Company;* Sidney Siegel, *Atomic Power Division, Westinghouse Electric Corporation.*

### Contributed Papers

**1. An undergraduate course on theory of measurement.** K. H. Moore, *Rensselaer Polytechnic Institute.*—Since 1946, the Physics Department at Rensselaer has offered an undergraduate course developed from a pre-war course entitled "Advanced Physical Measurements," in which a considerable fraction of the course time was devoted to the treatment and analysis of experimental data. In an attempt to fit physics majors better for their professional future, either as graduate students, as workers at the B.S. level in industrial and other laboratories, and even in the advanced laboratories of the physics curriculum (which has a distinctly professional cast), a full, four-semester-hour course was set up. Such courses are rare at the undergraduate level,—and it may well merit surprise that this one is required at second-term sophomore or first-term junior level. It is regularly patronized, as an option, by a sprinkling of senior and graduate students from other departments. The usual population is from 40 to 45. Experience has shown that, while a few difficulties arise, such a group can master and greatly profit from such a course. Descriptions of the syllabus and laboratory and a few case histories were presented.

**2. Scientific training in the Bureau of Ships.** A. W. Anderson, *Bureau of Ships, Navy Department.*—This paper outlined the history and efforts of the Bureau of Ships Committee for Education and Training. This committee is responsible for a comprehensive training program directed toward improving the professional stature of both the civilian and the military personnel of this Bureau. The above-mentioned program includes courses leading to advanced degrees, inservice courses and the junior engineer training project. Comments were made regarding accreditation by local colleges and universities, adequacy of the program and future plans.

**3. A modification of Rayleigh's method of measuring surface tension.** Paul F. Bartunek, *Lehigh University.*—Rayleigh's method of measuring surface tension depends

on a measurement of the wavelength of ripples formed on the surface of the liquid whose surface tension is to be determined. The method makes use of two electrically driven tuning forks of the same frequency, the one to set up the ripples, the other for stroboscopic viewing of the surface.[1] A set of apparently standing waves is seen whose wavelength can be determined by direct measurement using dividers adjusted over the surface. Due to technical developments since Rayleigh's time it is now possible to use simpler apparatus to obtain the same data. The modifications developed by the author while he was a member of the staff of Rensselaer Polytechnic Institute consisted of (1) the substitution of an a.c. driven vibrator in place of the tuning fork to set up the ripples and (2) the use of a stroboscopic neon flasher driven from the same a.c. line in place of the viewing fork of Rayleigh's original method. Troublesome intermittent contacts as well as one of the forks have thus been eliminated, reducing the amount of moving mechanism to a minimum. Excellent results have been obtained by advanced students using the simplified apparatus.

[1] Warsnop and Flint, *Advanced practical physics for students* (Methuen and Co., London, ed. 3), p. 137.

**4. Demonstrations of the use of microwaves in teaching physical optics.** C. L. Andrews, *New York State College for Teachers.*—In teaching the nature of electromagnetic waves, it is most effective to begin with waves that can be measured on an ordinary meter stick. Waves of 2500 megacycles (12 cm) are employed which involve sizes of apparatus most convenient to use in laboratory experiments and lecture demonstrations. The basic units are a transmitter and intensity meter each the size of a man's hand. The transmitter is an oscillator with two coupled resonant cavities employing a General Electric 2C43 disk-seal triode as an integral part of the cavities. The intensity meter is a crystal detector and microammeter. Demonstrations were made with microwaves of Young's experiment with interference from two secondary sources, Lloyd's mirror, standing waves, interference in thin films, diffraction by circular apertures and polarization.

**5. Count Rumford and the caloric theory of heat.** Sanborn C. Brown, *Massachusetts Institute of Technology.*—Count Rumford's classic cannon-boring experiment was by no means his only experiment to disprove the caloric theory of heat. He carried out a large number of experiments to refute the caloric arguments which included: the thermal expansion of water below 41°F, conduction of heat through a vacuum, evaporation and sublimation, the spontaneous mixtures of liquids at constant temperature, the weight of heat, and various experiments to show heat from mechanical work. This paper attempted to show that Count Rumford's reputation should be by no means based solely on his experiment with heat by friction, but on a long series of experiments extending over a period of thirty years, which attacked the caloric theory from many different points of view.

**6. Films showing repetitive phenomena—a progress report of the Committee on Visual Aids.** Mark W. Zemansky, *The City College of New York.*—In May, 1949, a questionnaire concerning the cooperation of the American Association of Physics Teachers with the McGraw-Hill Book Co. in the production of films for the teaching of first-year college physics was sent to about 2500 members of the association. There were about 900 answers. The results were: (1) Do you believe such films would be useful? Yes 746, No 17. (2) Silent or sound? Silent 115, Sound 687. (3) Is a price of $20 per film satisfactory? Yes 616, No 75. (4) Would you favor using such films in your teaching? Yes 774, No 19. The following topics were chosen, in order of preference: (1) Simple harmonic motion, (2) Longitudinal waves, (3) Waves through a diffraction grating, (4) Transverse waves, (5) *LRC* circuit oscillating, (6) Waves and rays through lenses and prisms, (7) Standing waves, (8) Induced current, (9) Beats, (10) Carnot cycle. It was pointed out that some satisfactory films already exist in sound and in geometrical optics. It was suggested that, as a result of the questionnaire, the committee proceed with its program and consider the production of films on topics in physics in which there are no film and no satisfactory lecture demonstration equipment.

**7. The preparation of students for employment at the bachelor's level.** Joseph Hilsenrath, *National Bureau of Standards.*—A preliminary report was given on the results of a survey of junior professional physicists, chemists, and engineers employed at the National Bureau of Standards and at the Naval Ordnance Laboratory. The data collected thus far showed a decided lack of professional awareness on the part of recent A.B. or B.S. graduates. This was manifested by their almost complete ignorance of the periodical literature in their own and allied fields, the extremely low incidence of membership in professional societies, and their disinclination to acquire skills in closely allied fields. The data collected were compared with similar data for more mature physicists and engineers in the government service and in a wide variety of industrial establishments. The ingredients for successful employment at the bachelor's level for a typical government research and development establishment were outlined. Among the important factors considered were: a firm grounding in mathematics and basic principles of classical physics, sufficient practice at solving problems, an awareness of the role of the professional literature in keeping abreast of the times, an inclination to acquire new knowledge in closely allied fields either through formal courses or self-study, an attitude toward his profession and his job which fosters a devotion to duty which extends beyond the 5 o'clock whistle.